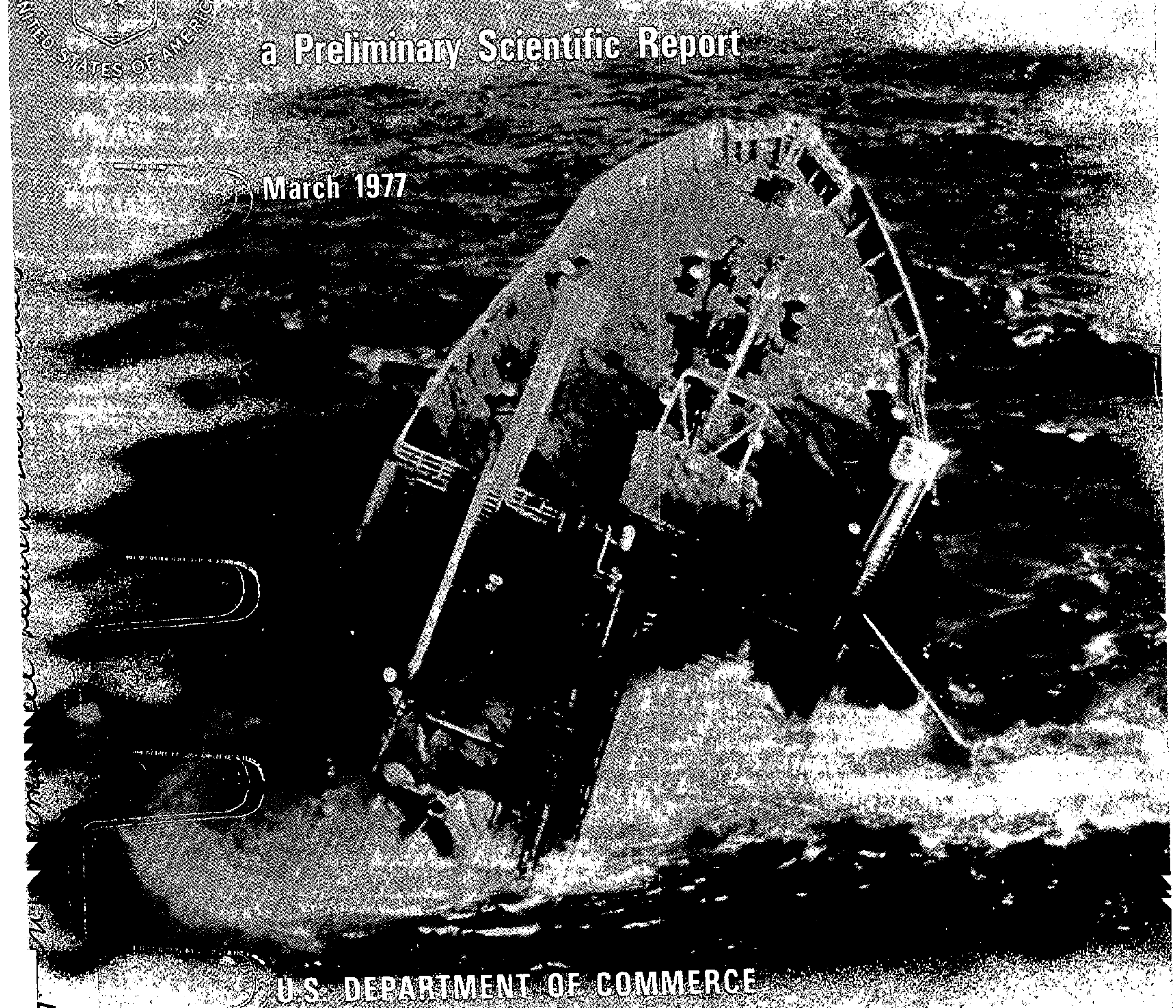
NOAA Special Report

The ARGO MERCHANT Oil Spill

a Preliminary Scientific Report

March 1977



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

NOAA Special Report: The ARGO MERCHANT Oil Spill - a Preliminary Scientific Report. Edited byPeter L. Grose and James S. Mattson. March 1977. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

ADDENDUM

Section 2.2.8, entitled "Tar Ball" Reports, on p. 40, the last paragraph of Section 5.2, Fate of the Oil, on p. 129, the March 10 entry on p. 7, and the third full paragraph on p. 7 of Appendix VIII, the Summary Fact Sheet, all refer to the finding of tar balls on Nantucket. Tar balls were indeed found on Nantucket in early March. However, tar balls came ashore on February 9 at Jamestown, Rhode Island (some weighing up to 15 to 20 pounds) and on Martha's Vineyard about February 17, and small tar balls came ashore on the outer reaches of Cape Cod in late February and early March. Tar balls from these three locations, Jamestown, Martha's Vineyard, and Cape Cod, were analyzed by infrared spectrophotometry by C. Brown of the University of Rhode Island. After comparing the tar balls with a sample of the *Argo Merchant* cargo, as well as with an artificially weathered sample of the cargo, Dr. Brown can state conclusively that these tar balls did not come from the *Argo Merchant*. They are too high in wax content to have been part of the *Argo Merchant* cargo. The Jamestown and Martha's Vineyard tar balls appear to be identical and the Cape Cod tar balls are similar, but not identical, to the other two. Samples of the Nantucket tar balls are being forwarded to Dr. Brown for analysis. (PLG JSM 4/6/77)

ERRATA

p. vi, line 2. "DOI," not "DOT."
p. 8, line 31. "conducted," not "collected."
p. 11, line 22. "Straughan," not "Strangham."
p. 21, line 23. "$69^{\circ}27.5'W$," not "$69^{\circ}24.5'W$."
p. 25, 12/19/76 entry. Current direction entry should be 205.
p. 39, line 18. "6 to 10 inches," not "6 to 10 feet."
p. 41, first URI entry, last column. "1.5%," not "1.5°," and "2% for oil," not "2% oil for oil."
p. 59, line 25. "Great Point," not "Grant Point."
p. 61, line 8. "VII-25," not "VII-55."
p. 69, line 40. "different," not "dirrerent."
p. 70, line 25. "about 2 hours," not "12- to 24-hours." (but no precise estimate can be made. Ed.)
p. 70, bottom line. "$210^{\circ}C$," not "$120^{\circ}C$."
p. 80, line 15. insert "ing" at beginning of line.
p. 81, line 3. insert "areas" between "likely" and "to."
p. 92, line 21. "Wellfleet" not "Wellflett."
pp. III-2 and III-20. Caption for photograph 36 should read "same as 35 but 204 seconds later. (Photograph 36 is printed inverted relative to photograph 35. Ed.)
p. V-11, line 11. Delete "with the exception of two samples, which were intercepted by USCG legal personnel," (Two *Bittersweet* samples were so intercepted. Ed.)
p. VII-12, 13, 14, line 1. "$^{\circ}$/kt," not "$^{\circ}$/kn."
p. VIII-7, col. 1, lines 1-7. (The divers found no oil on the bottom. The R/V Endeavor found oil near the bow section on Feb. 11, 1977. Ed.)

The ARGO MERCHANT Oil Spill

A Preliminary Scientific Report

Edited by
Peter L. Grose and James S. Mattson
NOAA Environmental Data Service
Center for Experiment Design and Data Analysis

Major contributing organizations:

U.S. Department of Commerce/National Oceanic and Atmospheric Administration
U.S. Department of Defense/Department of the Navy
U.S. Department of Interior/Bureau of Land Management
U.S. Department of Transportation/Coast Guard
U.S. Energy Research and Development Administration
Manomet Bird Observatory
Marine Biological Laboratory
Massachusetts/Fisheries and Game Division
National Aeronautics and Space Administration
National Science Foundation
University of Rhode Island
Woods Hole Oceanographic Institution

and a great number of participating organizations
as noted within the report

March 1977

U. S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

NOTICE

Mention of a commercial company or product does not constitute an endorsement by NOAA Environmental Research Laboratories. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

Published by:
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Boulder, Colorado 80302

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL RESEARCH LABORATORIES
Boulder, Colorado 80302

DATE: APR 04 1977

TO: Distribution

FROM: Rudolf J. Engelmann, Director
Outer Continental Shelf Environmental
Assessment Program

SUBJECT: Final Report Argo Merchant

Enclosed is the final report of the scientific response to the Argo Merchant Spill. The BLM-sponsored OCSEAP Spilled Oil Research Team played a significant role in the response and report preparation. We had just completed training of these NOAA/Coast Guard teams when the Argo Merchant ran aground and were able to use this training to good advantage in responding to the spill.

This report only covers the initial response to the spill. Long-term effects studies are being implemented under other sponsorship and results of that work will not be available for some time.

- END -

EXECUTIVE SUMMARY

The tanker *Argo Merchant* carrying 7,700,000 gallons of No. 6 fuel oil went aground on Fishing Rip, 29 nautical miles southeast of Nantucket Island, Massachusetts, at 0600 EST on December 15, 1976. Despite attempts to refloat the tanker, it began to leak oil and, at 0835 on December 21, broke in half after a battering by gale force winds. By the next day, after the ship had broken again, most of the oil it carried was drifting at the mercy of winds and currents. The bow section, which still had some buoyancy and was thought to contain some remaining cargo, started drifting away from the other two pieces of wreckage. Despite attempts by the U.S. Coast Guard to remove the buoyancy by holing the floatation compartments on December 31, the bow section drifted southeast into deeper water under the influence of the severe currents in the area. On February 8, 1977, the bow section was relocated 1 mile to the southeast and was found to be empty of oil. What started as another tanker going aground ended up as one of the largest oil spills in U.S. history.

The grounding of the *Argo Merchant* triggered intense scientific activity between December 15, 1976, and February 12, 1977, aimed at describing the movement and fate of the oil released by the tanker as a first step in the long process of assessing the ecological effects of the spill. This activity was centered on the U.S. Coast Guard's operations at its Cape Cod Air Station, and was coordinated by the U.S. Coast Guard, the National Oceanic and Atmospheric Administration (NOAA), and academic scientists from the oceanographic research institutions in Massachusetts and Rhode Island. Participating agencies, in addition to the U.S. Coast Guard and NOAA, included Alaska Department of Environmental Conservation; U.S. Navy, including the Naval Underwater Systems Center, Department of Defense; Bureau of Land Management and the U.S. Geological Survey (USGS), Department of the Interior; Environmental Protection Agency; Energy Research and Development Administration; Manomet Bird Observatory; Marine Biological Laboratory; Massachusetts Division of Fisheries and Wildlife; Massachusetts Institute of Technology; the Universities of Massachusetts, Rhode Island, and Southern California; and Woods Hole Oceanographic Institution.

During the week after the grounding, both NOAA and Woods Hole Oceanographic Institution (WHOI), recalled research vessels from scheduled operations to undertake special cruises designed to determine the fate of the oil and to make the first assessments of the impact of the spilled oil on the ecology of the lucrative fishing grounds. Six biology stations were occupied by scientists from NOAA's National Marine Fisheries Service (NMFS) on the *Delaware II* and three stations were occupied by WHOI and NOAA scientists on the *Oceanus* to assess how much oil had entered the water column and sediments. In the weeks that followed, over 200 water and sediment samples were acquired during cruises on U.S. Coast Guard, NOAA, WHOI, USGS, and University of Rhode Island vessels. Forty-three additional biology stations, at which fish and shellfish samples were obtained, were occupied during a second NMFS cruise. The culmination of the initial field activities was a benthic survey that encompassed the entire Continental Shelf bottom over which the *Argo Merchant* oil had passed. This bottom survey was completed in two cruises by oceanographers from the University of Rhode Island (URI), NOAA, and the Coast Guard on URI's *R/V Endeavor*, the second cruise ending on February 12, 1977. Another cruise of the *Endeavor* began on February 21, 1977, to delineate the extent of the bottom contamination in the vicinity of the sunken bow section of the *Argo Merchant*. Further field programs are planned by NMFS to continue the long-term assessment of the spilled oil on the ecology of Nantucket Shoals and Georges Bank.

Prelininary chemical analyses for oil content of all water and sediment samples taken up until February 12, 1977, have been completed. Selected samples of fish, shellfish, water, and sediments have been sent to the NOAA National Analytical Facility in Seattle, Washington, for more detailed study. Biological studies based mainly on sampling at the six stations occupied during the first cruise of the *Delaware II* (DE 76-13) are being carried out by NMFS scientists. Neither the chemical nor biological studies have been completed. Work is continuing by all concerned toward final assessment of the fate and impact of the oil spilled from the *Argo Merchant*. With these cautions in mind, the following *preliminary results* are presented:

- The oil from the *Argo Merchant* stayed on the ocean surface, with the exception of the "cutter stock," which entered the water column, and an as-yet undetermined amount of whole oil that was mechanically worked into the bottom in the immediate vicinity of the wreckage. The cutter stock, which comprised 20 percent of the oil, was found in the water column in concentrations up to 250 parts per billion. The highest levels were observed only beneath fresh oil slicks, and were reduced to background levels by turbulent mixing in a few days.

- Oil in significant amounts has not been found in the sediments to date, except within 10 miles of the bow section, where concentrations up to 100 parts per million were measured.

- Most of the oil remained on the surface and moved offshore under the influence of the prevailing west winds. Surface oil was never observed north of 41°21' or west of 70°10', nor was it observed within 15 miles of any land. Modeling efforts were successful in predicting the offshore movement of the surface oil, primarily because the movement was controlled by predominantly offshore winds while the complicated circulation of the nearshore areas and Nantucket Shoals played only a minor role.

- There is evidence of oil contamination in fish, shellfish, ichthyoplankton, and zooplankton populations in the area of the spill. Mortalities of developing cod and pollock embryos in eggs contaminated with oil were observed. No. 6 fuel oil caused significant mortalities of cod embryos in laboratory experiments conducted by NMFS and collaborating scientists from EPA and the University of Kiel. Noticeable decreases in the abundance of sand launce larvae, which may have been caused by oil, were observed in the spill zone. Large numbers of zooplankters, which are an important food of larval and adult fish, were contaminated with petroleum hydrocarbons similar to No. 6 fuel oil, indicating impact on an important pathway in the food web of the Nantucket Shoals ecosystem. The extent of this impact is under investigation. Much of the oil in the copepods was in the form of fecal pellets. These pellets are excreted into the water column, settle to the bottom, and may be concentrated in such benthic filter-feeders as mussels, scallops, and quahogs. Adverse physiological effects were also observed in reduced respiration of scallops, mussels, and an ionic imbalance of blood serum in blackback and yellowtail flounders. The implications of the above results for long-term effects are unclear Additional extensive surveys and laboratory tests will be required to clarify preliminary findings.

- Of the seabirds affected by the surface oil, the highest mortality was observed among Murres. Marine mammals did not appear to be affected by the surface oil in the few cases where they were seen in the vicinity of the oil. These findings, however, are based on very limited observations.

- The No. 6 fuel oil from the *Argo Merchant* formed pancakes of oil that tended to increase in thickness as they aged. These pancakes were observed to have flat bottoms, and they did not appear to be tapered towards their edges. The affected surface area was not solidly covered by a continuous film of oil but rather by thick pancakes, very thin oil film (sheen), and large open areas of water. Several direct measurements of the velocity of the oil pancakes relative to the surface water indicated that this differential velocity was about 1 percent of wind speed in a downwind direction. The oil sheen appeared to be generated by the oil in the pancakes and moved at a slightly lower speed.

- Sufficient data were collected during the oil spill to allow the generation of a data set that can be used for hindcasting the oil movement. These data include meteorological observations, current observations at several locations in the spill area, a time history of the area covered by oil, as well as data on the amounts and fractions of the oil, as a function of time and space, that entered the water column. Analyses of these data will also lead to the development of improved algorithms describing the fate of oil that can be incorporated into predictive models.

Much of the success of the research activities conducted in response to the oil spill can be attributed to the interest and cooperation of the Federal On-Scene Coordinator, Captain Lynn Hein of the U.S. Coast Guard, as well as to the deliberate effort to coordinate the research rather than allowing it to be fragmented and independent. Captain Hein was not only actively involved in the research activities, but also made operational resources available for research purposes on a noninterference basis, particularly logistic support by Coast Guard aircraft and ships. This contribution by the Coast Guard cannot be overestimated. Without it, research personnel would not have had the necessary information for operational planning and would have had only limited access to the spill site for sampling and other investigations.

The coordination of the research activities began almost immediately after the *Argo Merchant* had run aground and the potential for an oil spill was apparent. Marine scientists from NOAA and the U.S. Coast Guard had outlined a contingency research plan for just such an event under the sponsorship of the Bureau of Land Management, DOT, through the Outer Continental Shelf Environmental Assessment Program managed by NOAA. It was the existence of this plan, as well as the intense participation of 14 NOAA and U.S. Coast Guard staff members who were thoroughly familiar with the scientific procedures and goals outlined in the plan, that enabled a concentrated, comprehensive research effort to begin in earnest only 27 hours after the grounding. On December 17, coordination meetings were held with marine scientists from local research institutions to determine the resources available and to develop an immediate sampling program. Constant contact was maintained between the participating organizations to ensure that activities remained coordinated.

On January 3 and 4, 1977, a meeting of the scientists involved in investigating the *Argo Merchant* spill was convened to develop criteria for the next phase of investigation into the fate of the oil. As a result of that meeting, a single chemical analysis network was agreed upon for the analysis of all the water sediment and biota samples that had been taken up to that date and would be taken in the next 6 weeks. The meeting also resulted in a plan for a survey to culminate the initial field activities by assessing the amount of oil that remained in the water column and determining which benthic areas were contaminated. Because of the continued coordination among the participating scientists, the research activities remained cohesive and were able to yield the results summarized above. Although preliminary in nature, these results are nevertheless quite definitive and broad in scope.

In conclusion, the outcome of the *Argo Merchant* oil spill appears to have been fortunate in several respects: (1) the winds were almost continuously offshore, preventing the oil from coming on the beaches; (2) the density of the oil was low enough so that it did not sink and contaminate the bottom; and (3) the spill occurred in the winter, when biological activity, productivity, and fishing activities are relatively low. At another time, the effects of a similar oil spill might have been much more serious.

PREFACE

The grounding of the *Argo Merchant* on Nantucket Shoals off the coast of Masachusetts on December 15, 1976, and the subsequent discharge of oil during the breakup of the vessel resulted in one of the largest oil spills off the shores of the United States. The resulting oil spill occurred in one of the most productive fishing grounds of the world and threatened to be a major disaster not only to the marine ecosystem but also to the livelihood of our fishermen. In response to this potential disaster were brought to bear the talents and resources of Federal and State organizations and private institutions in an unprecedented effort to determine the movement and behavior of the spilled oil and to assess its impact upon the marine ecosystem.

We are just now establishing the initial assessment of the oil spill upon the area of Georges Bank and Nantucket Shoals and the resources of that area. It is a complex ecosystem.

This report presents the available results from the investigations carried out to date by the many groups involved in the initial assessment of the distribution of the *Argo Merchant* oil spill and its impact. For the many Federal, State, and private activities requiring information about the oil spill and its consequences the report is intended to provide a unified summary of the studies that are being or have been carried out, the types and distribution of data, and such analyses and results as are now available.

The results which are included within the report are mostly those of the individual investigators and groups that responded to the *Argo Merchant* incident. Many of them must be considered preliminary, particularly with respect to the impact upon the fishery resources of the area, and must await further study. However, we already have gained a much greater understanding of the behavior of oil spills and their impact upon the ecosystem so as to be better able to respond to such incidents in the future.

I would like to express my appreciation to the many individuals who dedicated long and hard hours, often under extremely adverse conditions, addressing this serious threat to our environment and valuable resources.

Robert M White

ACKNOWLEDGMENTS

When the *Argo Merchant* ran aground, there was virtually no organized plan for conducting research on the spilled oil with the exception of an outline plan of NOAA/Coast Guard Spilled Oil Research Program funded by the Bureau of Land Management, Department of Interior. As the word of the potential disaster got around by phone calls and the news media, people, agencies, and institutions volunteered their services and responded to requests for help. Within a few days a coherent research plan specific to the *Argo Merchant* was put together by participating scientists and implemented. This plan focused on gathering data to improve models that predict spilled oil behavior and on assessing the impact of oil on the local biological communities. The speed of response by the many agencies involved and the resources that were brought to bear on the problem was amazing. Planes, ships, and facilities were diverted from their normal scheduled tasks to aid in the emergency.

This report was assembled from the contributions made by the numerous government agencies, private and state institutions, and industrial groups involved in assessing the fate and impact of the *Argo Merchant* oil. The broad spectrum of talent which participated in the research is overwhelming, as can be seen by a glance at Appendix I. Many of the participants voluntarily gave up their vacations and altered their holiday plans to help in the investigation. For the last 2 months many of these same people have been working day and night, not only to collect data for research but also to analyze them and present them in preliminary form. This document witnesses the unselfish efforts of these people.

Some individuals deserve special credit for their part in producing this report: Carolyn Rogers who served as the contact and assembled the material from the National Marine Fisheries Service; Eva Hoffman who served in the same capacity from the University of Rhode Island; Elaine Chan of the Spilled Oil Research Team, whose tireless capacity for recording events and statistics prevented many items of research from being lost during the hectic times of the contingency operations; John Mugler, Jr., of NASA Langley Research Center, who coordinated NASA's efforts. Kathy Kidwell of EDS generated most of the graphics both for the draft preliminary report and this report. Rosalie Redmond from the NOAA Environmental Research Laboratories not only spent a grueling 2 weeks working around the clock typing the draft preliminary report, but she also gave up her vacation to come to Cape Cod immediately after Christmas, leaving her family behind to do so. Finally, Kate Bradley, Gloria Thompson, and Clemmie Edwards gave up their off duty time to retype the draft report to incorporate numerous changes and revisions into the final manuscript.

Contents

LIST OF ABBREVIATIONS

ADEC	-	Alaska Department of Environmental Conservation
AMSI	-	Aero-Marine Surveys, Inc.
AOML	-	Atlantic Oceanographic and Meteorological Laboratories (NOAA)
ART	-	Airborne Radiation Thermometer
AST	-	Atlantic Strike Team
BLM	-	Bureau of Land Management (DOI)
CEDDA	-	Center for Experiment Design and Data Analysis (NOAA)
USCGC	-	U.S. Coast Guard Cutter
DOI	-	Department of the Interior
DOT	-	Department of Transportation
EDS	-	Environmental Data Service (NOAA)
EPA	-	Environmental Protection Agency
ERDA	-	Energy Research and Development Administration
ERL	-	Environmental Research Laboratories (NOAA)
FAA	-	Federal Aviation Administration
GEOS	-	Geodynamics Experimental Ocean Satellite
IR	-	Infrared
Landsat	-	Land Satellite
MESA	-	Marine Ecosystems Analysis
MIT	-	Massachusetts Institute of Technology
MSO	-	Marine Safety Office (USCG)
NAA	-	New England Airphoto Associates, Inc.
NASA	-	National Aeronautics and Space Administration
NDBO	-	NOAA Data Buoy Office
NEFC	-	Northeast Fisheries Center (NOAA)
NESS	-	National Environmental Satellite Service (NOAA)
NMFS	-	National Marine Fisheries Service (NOAA)
NOAA	-	National Oceanic and Atmospheric Administration
NOS	-	National Ocean Survey (NOAA)
NUSC	-	Naval Underwater Systems Center
NWS	-	National Weather Service (NOAA)
OSC	-	On-Scene Coordinator
OCSEAP	-	Outer Continental Shelf Environmental Assessment Program
RFC	-	Research Facilities Center (NOAA)
SAI	-	Science Applications, Inc.
SOR	-	Spilled Oil Research Team
URI	-	University of Rhode Island
USAF	-	U.S. Air Force
USCG	-	U.S. Coast Guard
USGS	-	U.S. Geological Survey
USN	-	U.S. Navy
WHOI	-	Woods Hole Oceanographic Institution
XBT	-	Expendable Bathythermograph

1. INTRODUCTION

1.1 Purpose of Report

The purpose of this document is to provide a preliminary account of the physical, chemical, and biological studies initiated by numerous federal and state agencies, and private institutions during the period immediately following the grounding of the *Argo Merchant* on Nantucket Shoals on December 15, 1976.

At 0600 EST, December 15, 1976, *Argo Merchant*, carrying 7,700,000 gallons of No. 6 fuel oil, went aground on Fishing Rip, 29 nautical miles southeast of Nantucket Island, Massachusetts. Despite attempts to refloat the tanker, it began to leak oil, and at 0835 on December 21 the battered tanker broke in two. The subsequent oil spill was one of the largest in United States history.

The National Oceanic and Atmospheric Administration (NOAA) has established a NOAA-U. S. Coast Guard Spilled Oil Research (SOR) Team to provide rapid research response in the event of accidental oil spills within the continental United States by studying the physical-chemical movement of various classes of oil at sea under a variety of oceanographic and meteorological conditions, in support of both predictive and operational oil spill trajectory models. The SOR Team is made up of scientists from NOAA, the U. S. Coast Guard and the Alaska Department of Environmental Conservation. Within 4 hours of the grounding of the *Argo Merchant*, the SOR Team was notified of the potential major oil spill.

After arrival on the scene, the first team members were informed that the USCG would provide logistics supporting research. In return, the SOR Team would provide information to the On-Scene Coordinator, as well as assistance in coordination between the On-Scene Coordinator and the scientific community involved in research during the spill. Numerous federal and state agencies, as well as state and private research organizations, participated in a combined research effort.

This report documents the cooperative investigations that were undertaken immediately following the grounding of the *Argo Merchant*. It describes completed and continuing research on the physical, chemical, and biological processes associated with the spill, and provides a preliminary assessment of the spill.

1.2 Historical Background

In order to place the *Argo Merchant* spill into proper perspective, it is worthwhile to digress somewhat and examine marine oil pollution in its entirety. Sightings of tar balls at sea, oil slicks of unknown origin, and beach pollution by oil have been reported with increasing frequency in the pages of scientific journals and daily newspapers since 1967. After the 1967

Torrey Canyon grounding and the Santa Barbara Channel blowout in 1969, the United States government began to take measures to meet the demands of the public for clean beaches and waterways, as evidenced by the adoption of legislation designed to assign responsibilities for the cleanup of oil spills, determining the source, and assessing financial liability.

During the winter of 1976-77, when the *Argo Merchant* went aground on Nantucket Shoals, the *Grand Zenith* disappeared off New England, and barges were going aground in Buzzards Bay and the Hudson River, it may have seemed as though some diabolical scheme were afoot to wreak havoc on U.S. shores. Yet, on November 5, 1969, the tanker *Keo*, carrying 210,000 barrels of No. 4 fuel oil, 21,000 barrels more than the *Argo Merchant*, broke in half 120 miles southeast of Nantucket, Massachusetts, but few scientists remembered that accident when they predicted the devastation of Georges Bank fisheries by *Argo Merchant* oil. Less dramatci, but important nonetheless, were spills of No. 6 fuel oil into Buzzards Bay on February 9, 1969, from the tanker *Algol*, and into Narragansett Bay in April 1973 from the tanker *Pennant*. In the 1969 Buzzards Bay spill, up to 4,000 barrels of No. 6 fuel oil spilled over a period of days, in subfreezing temperatures, 45-knot winds, and 8- to 20-foot seas. In the 1973 *Pennant* spill, over 2,000 barrels of No. 6 fuel oil came ashore in Narragansett Bay near Bristol, Rhode Island, with tar balls and "pancakes" of oil hitting Conimicut and Gaspee Points. The *Argo Merchant* grounding on December 15, 1976, was not the first instance of oil pollution in that area. It was not even the largest one, being somewhat smaller than the *Keo* spill in 1969, and it is certainly not going to be the last such incident off the coast of New England.

In 1973, the National Academy of Sciences (NAS) organized a Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment. This workshop identified the sources of petroleum hydrocarbons entering the sea as follows: natural seeps, losses during offshore production, transportation (operations and accidents), refineries, atmospheric input, municipal wastes (domestic and industrial), urban runoff, and river runoff. While there are many contributors to marine pollution by oil, and some of them are quite substantial, marine transportation is responsible for the largest single share (35%) as shown in Figure 1-1 based on the findings of the NAS Workshop. Of this 35%, one-seventh is derived from accidents involving vessels.

The persistence of oil introduced into the marine environment has long been a subject of controversy. The 1957 *Tampico* wreck resulted in a spill of 60,000 barrels of diesel fuel in a small bay on the Pacific coast of Baja California. W. North of California Institute of Technology described the recovery of the marine life in this bay as well underway within 1 year. Ten years after the accident, the bay appeared to have been restored to something approaching its original state, though the dominant organisms may have been different from the ones predominating before the spill. It is worth noting that news of the *Tampico* grounding did not reach marine scientists until three weeks after the accident.

There have been other accidents where little damage to the local environment was apparent, even with materials more persistent than the diesel fuel spilled by the *Tampico*. According to some investigators, no long-term

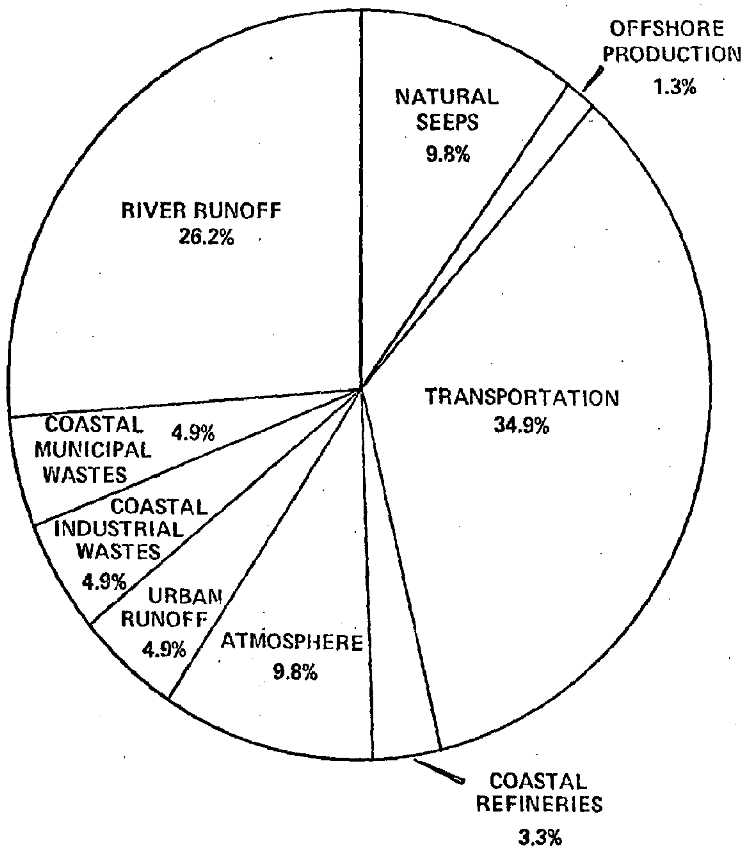


Figure 1-1. Contributions to marine pollution by oil.

effects were observed in the biota of the Santa Barbara Channel area after the 1969 blowout. Winter rains were abnormally severe during the Santa Barbara Channel accident, causing huge quantities of clay mineral particles from the Ventura and Santa Clara Rivers to flow into the Channel, sinking the oil slick on contact. The sunken oil was reworked by bottom currents the next year, until most of it resided in the nearly anaerobic Santa Barbara Basin. The sheer volume of sediment input to the Channel that winter covered the oil deposits to a depth of several centimeters within a few months, making the oil inaccessible to all but burrowing benthic organisms. In addition, oil beached along the Santa Barbara Channel coast-line arrived after the beaches had been cut back severly by the longshore currents prevalent in that area in the winter, so that these oil deposits were buried by several centimeters of sand when the beaches were rebuilt later that year. Continued tidal action dispersed the beached oil vertically within the sand, thus returning the beach to near-normal conditions within a year or two. Sunken oil is not really gone, just out of sight, and oil on the sea bottom could adversely affect local fishing interests for some time after an accident. Shrimp fishermen in the San Francisco area picked up oil in their nets for several weeks following the collision of the *Arizona Standard* and the *Oregon Standard* under the Golden Gate Bridge in 1971. This oil was a heavy residual fuel oil spilled in a highly turbulent environment. As it lost whatever volatile components it had and its density approached that of seawater, the remaining fractions were rapidly dispersed through the water column. A similar observation was made after the wreck of the *Arrow* in Chedabucto Bay, Nova Scotia, with particles of oil found in the water column at substantial distances from the wreck.

Using the worldwide accident data published by Lloyds of London, Keith and Porricelli (1973) published an analysis of 1,416 tanker accidents that occurred in 1969 and 1970. Of these accidents, 266 reported measurable outflows of oil, and an analysis of these documented cases presents some picture of the causes of accident-related oil pollution. Keith and Porricelli found that this accident-related input of oil to the sea during 1969 and 1970 was somewhere between 427,000 and 447,000 metric tons, or about 218,000 metric tons (1,526,000 barrels) per year. This compares well with the NAS Workshop estimate of 300,000 metric tons per year which includes pollution from non-tanker accidents (100,000 metric tons per year) as well as tanker accidents (200,000 metric tons per year). Table 1-1 summarizes the magnitude of oil pollution for each class of accident during the 2-year period.

Table 1-1. Vessel-related oil pollution worldwide by accident type, 1969-70 (from Keith and Porricelli, 1973)

Type of casualty	Oil released, barrels/2 yrs	Percent of total
Structural failure	1,510,355	49.3
Grounding	882,042	28.8
Collision (ship-to-ship)	243,733	8.0
Explosion	242,137	7.9
Breakdown*	116,634	3.8
Ramming (ship-to-object)	33,124	1.1
Fire	30,716	1.0
Other	4,536	0.1
Totals	3,063,277	100.0

*Mechanical breakdown that led to eventual grounding and breakup of the tanker.

Keith and Porricelli point out that the volume of oil pollution caused by a grounding is likely to be three to four times that expected from a collision, primarily because of the tendency to hole many tanks during a grounding, often leading to the total loss of a vessel and its cargo. In their analysis, they found that the smallest tankers (10,000 to 20,000 deadweight tonnage) were responsible for the highest relative frequency and magnitude of oil pollution incidents, and that the very large cargo carriers (200,000 deadweight tonnage) were responsible for much less pollution per deadweight ton afloat than the average tanker. The *Argo Merchant* carried about 27,000 tons. Keith and Porricelli's (1973) analysis of the vintage of tankers involved in accidents showed that vessels over 17 years old were responsible for more than their share of accidental pollution incidents, and about half of those were due to structural failures. The *Argo Merchant* was 23 years old when it ran aground on Nantucket Shoals.

In 1970, the Dillingham Corporation carried out a study of the "major" oil spills that had taken place worldwide between 1955 and 1970. Seventy-five percent of the major incidents that took place during those 15 years involved vessels, and 90 percent of the vessels involved were tankers. In that study, it was concluded that the likely source of a major spill in the United States coastal waters would be an oil tanker carrying crude oil or residual fuel. Because of the high traffic in and around port facilities, it was also predicted that major spills will most often occur within 10 miles of shore and within 25 miles of the nearest port. The Dillingham report predicted that the median volume of a major spill would exceed 5,000 barrels, the median size spill in the 1955-1970 period being 25,000 barrels. The *Argo Merchant* spill, on the high side of that estimate, comes in at 189,000 barrels.

Since the U.S. Coast Guard began its Pollution Incident Reporting System (PIRS) in 1971, it has been possible to examine oil spills in U. S. waters in substantial detail. For the three years in which breakdowns by spill size are available (1972, 1974, 1975), there were an average of only 24 spills per year that exceeded 100,000 gallons (2,381 barrels) in size. These 24 "major" oil spills per year constituted only 0.3% of the total number of spills, but produced twothirds (68.7%) of the total oil pollution each year, averaging about 11,400 barrels per spill. The PIRS reports also indicate that, during the 1971-1975 period, oil tankers and tank barges were responsible for discharges averaging 116,139 barrels per year or 29% of the average annual total each year; that crude oil and residual fuels accounted for 60% of all of the petroleum pollution in the United States during 1973-1975 (crude oil alone, 49%); and that spills in ports, coastal estuaries, bays and sounds, and non-navigable waterways accounted for 87% of the total oil discharged in 1971-1975. The PIRS reports do not completely account for oil spills in the contiguous zone or on the adjacent high seas.

For all practical purposes, it appears that the predictions made by Dillingham Corporation in 1970 remain true to this day. The *Argo Merchant* oil spill was neither particularly unusual nor unexpected. The volume of oil discharged (189,000 barrels) can be considered somewhat exceptional, but the nature of the accident was not unusual. The *Argo Merchant* accident was a highly visible example of an oil pollution problem that involves thousands of spills each year, usually over 10,000 each year in U.S. waters alone. A study of the *Argo Merchant* oil spill is a study of a chronic national, and international, problem; one that shows no signs of going away in the foreseeable future.

1.3 Chronology of Events

Activities set in motion in response to the grounding of the *Argo Merchant* and the coordination of scientific research efforts by the NOAA-USCG SOR Team from the time of the accident until February 12, 1977, are summarized below. A full chronology of key events up to December 31, 1976 is contained in Appendix II. Hours are Eastern Standard Time.

<u>December 15</u> — The *Argo Merchant*, carrying 7.7 million gallons of No. 6 fuel oil aground on Nantucket Shoals, resulting in one of the largest oil spills in United States history. Distress call received by USCG at 0700. USCGC *Vigilant* on scene. National Weather Service starts special forecasts for Fishing Rip area. NOAA-USCG SOR Team sets up headquarters in Hyannis, Massachusetts, at 2100 and begins coordination of scientific efforts.

<u>December 16</u> — USCG assumes full control and responsibility for the *Argo Merchant* under Intervention Convention at 1457. Weather conditions worsen. All personnel evacuated from the tanker at 2300.

<u>December 17</u> — SOR Team personnel attend coordination meeting at 1600 at Woods Hole Oceanographic Institution (WHOI) to develop scientific response.

<u>December 18</u> — USCG reports large amount of oil spilled and geysers of oil shooting upward. Heavy oil plume 7.5 miles long to the northwest. Ship listing 20 . Seas building up. Oil "pancakes" sighted by USCG 27 miles east of ship.

<u>December 19</u> — USCG reports that 1.5 million gallons of oil have entered the sea and that the *Argo Merchant* is sinking at stern. Supertanker fenders rigged along side the tanker at 1430 in preparation for offloading to barges.

<u>December 20</u> — WHOI vessel *Oceanus* begins cruise 19.

<u>December 21</u> — Heavy seas. *Argo Merchant* splits aft of kingpost, releasing approximately 1.5 million gallons of oil. *Oceanus* returns to Woods Hole after taking water and sediment samples to northeast of slick.

<u>December 22</u> — Bow section of *Argo Merchant* splits again. NOAA vessel *Delaware II* and USCGC *Evergreen* depart for scientific cruises. Scientific meeting in Boston called by EPA Administrator.

December 23	U. S. Navy divers take movies of underside of slick and bottom. No visible oil on bottom.
December 24	*Delaware II* completes cruise DE 76-13.
December 25	Forecast of onshore wind condition. USCG contractors notified of possible beach cleanup operation at 1600. Overflight on which "pancake 1" is identified.
December 26	Forecasting of onshore winds continued. 3000 drift cards deployed as early warning system at 0940 between slick and shore. "Pancake 1" located again by USCG overflight.
December 27	Another 3000 drift cards deployed between spill and Nantucket at 0912. First attempt to burn oil. *Evergreen* cruise ends. *Oceanus* cruise 20 begins.
December 28	USCGC *Bittersweet* replaces *Vigilant* as on-scene vessel. *Endeavor* cruise EN002 begins. On-Scene Coordinator's status meeting and press conference at 1000.
December 29	Bow section starts to move under the influence of current.
December 30	*Endeavor* cruise EN002 ends.
December 31	*Argo Merchant* bow section holed by 20-mm cannon fire to prevent drifting and remove navigational hazard. Second experiment to burn oil from the *Spar*.
January 3	Coordination meeting at WHOI. Bow section observed moving again.
January 4	Coordination meeting at WHOI continued. *Delaware II* cruise DE77-01 begins.
January 9	Bow section totally underwater.
January 10	*Delaware II* cruise DE 77-01 ends.
January 26	*Endeavor* cruise EN003 begins.
January 29	*Endeavor* cruise EN003 terminated because of weather.
February 8	Bow section of *Argo Merchant* relocated 1 mile to the southeast of stern and found empty of oil. *Endeavor* cruise EN004 begins.
February 11	Oil found in bottom sediments near now section.
February 12	*Endeavor* cruise EN004 ends after completing initial benthic survey.
March 10	"Tar balls" up to a foot in diameter reported washing ashore on Nantucket Island's southwest coast. Samples sent to WHOI to determine whether original is crude or refined petroleum; analysis will not be able to establish whether the material came from the *Argo Merchant* spill or from another spill of No. 6 fuel oil.

1.4 Participants

Representatives of the National Oceanic and Atmospheric Administration (NOAA), including personnel from the Environmental Research Laboratories (ERL), Environmental Data Service (EDS), and National Marine Fisheries Service (NMFS), worked on the scene of the grounded *Argo Merchant*. The National Weather Service, although not on scene, responded to the spill with special weather forecasts.

The NOAA-U. S. Coast Guard Spilled Oil Research (SOR) program is managed by the Outer Continental Shelf Environmental Assessment Program Office of NOAA's Environmental Research Laboratories and is funded in part by the Bureau of Land Management, Department of the Interior. The SOR Team, in addition to conducting its own limited research, assisted in the coordination of research activities launched in response to the oil spill at the request of the Federal On-Scene Coordinator. These research activities include photographically documenting the behavior of the oil, and measuring oil velocities and oil-water differential velocities from overflights in chartered aircraft and USCG planes and helicopters. The SOR Team dropped drift cards and deployed a satellite-tracked buoy as part of oil-mapping efforts. The team also made surface current measurements as input for trajectory predictions, and sampled the oil and water column over time to study the effect and extent of weathering.

Special forecasts were provided by the National Weater Service for the Nantucket Shoals - Fishing Rip area in support of the OSC. Two to six forecasts per day were available on demand commencing at noon December 15. Hourly surface weather data were collected for the Massachusetts coast.

The National Marine Fisheries Services (NMFS) conducted two cruises on the NOAA research vessel *Delaware II* in the area of the grounding, taking temperature profiles and sampling fish, plankton, water and sediments. Samples of fish and invertebrates were selected for hydrocarbon analysis. NMFS analyzed the biological samples for impact of *Argo Merchant* oil and collected a port survey to assess the impact on fishing activities.

The Center for Experiment Design and Data Analysis (CEDDA) of NOAA's Environmental Data Service carried out a modeling study based on historical wind records and local current measurements at the request of the OSC on December 28. They also supplied additional manpower to augment the Spilled Oil Research Team's efforts at Cape Cod as did NOAA's Environmental Research Laboratory. The NOAA Data Buoy Office made satellite tracked drifting buoys available for use in tracking oil and measuring currents. CEDDA personnel prepared an interim report on January 3, 1977, for use by all participating investigators and also prepared this report.

The U. S. Coast Guard (USCG) served as the focal point for all operational activities through the Marine Safety Office, First Coast Guard District, Boston, Massachusetts, with support from the Coast Guard Oceanographic Unit, Washington, D. C., and in addition participated in the research program through the Coast Guard Research and Development Center, Groton, Connecticut.

Operational activities were directed by Captain Lynn Hein, the Federal On-Scene Coordinator (OSC) from the USCG Cape Cod Air Station. Research-related activities conducted by the OSC included the collection of hourly meteorological data from the cutters *Vigilant* and *Bittersweet*, which were stationed at the wreck site from December 15 to 31, 1976. Following brief instructions from the SOR Team, officers on these cutters collected water samples, from beneath the spilled oil for petroleum hydrocarbon analysis. The USCG personnel also conducted surveillance flights to map the extent of the spilled oil and to measure sea surface temperatures. Based on modeling inputs and mapping information, they generated daily predictions of the location of the oil. In addition, they supplied logistics on Coast Guard aircraft and ships, on a noninterference basis, to allow scientific investigators access to the site of the spill.

The USCG Research and Development Center was active in assisting the OSC, as well as in conducting research on the spilled oil. Center personnel supplied short and long-term predictions of oil movement through modeling efforts, and conducted an experiment to burn the oil. They conducted a research cruise from the cutter *Evergreen* to collect water and sediment samples for PHC analysis, and photographed the bottom in an effort to locate oil contamination. R. Jadamec was responsible for the hydrocarbon screening of all water and sediment samples collected by participating investigators. Center personnel also played an active role on the SOR Team.

The U.S. Navy's Atlantic Fleet Audio Visual Command provided a team of divers equipped for underwater cinematography and photography at NOAA's request. Diving under the floating oil, they photographed and described the morphology of the underside of the slick, and determined the potential implications to fisheries by observing the presence or absence of visible oil in the water column and on the sea bottom. The Naval Underwater System Center also supplied a current meter mooring, which was implanted from the *Endeavor*.

The Bureau of Land Management (BLM), Department of the Interior, provided financial support for the NOAA-Coast Guard Spilled Oil Research Program as well as several contractors involved in the North Atlantic Georges Bank Continental Shelf environmental studies program. Aero-Marine Surveys, Inc. Raytheon and EG&G, all BLM contractors, augmented USCG slick mapping efforts and temperature and current observations. They also carried out oil slick characterizations from overflights.

The National Aeronautics and Space Administration (NASA) provided high altitude photographic overflights, Landsat coverage checks, and false color infrared photomosaic composites with the assistance of the U.S. Air Force Tactical Air Command. Significant wave heights were measured by the Geodynamics Experimental Ocean Satellite. NASA also computed drifting buoy positions from Nimbus-F data and facilitated their delivery for on-scene use in flight planning.

Under contract to the Environmental Protection Agency, the New England Air Photo Association conducted photographic overflights of the *Argo Merchant* spill, from which EPA constructed natural color mosaics of the oil slick.

The U.S. Geological Survey (USGS) at Woods Hole emplaced two current meter systems, which recorded suspended sediment conditions, current speed and direction, and water depth while photographing the bottom. Six current meters were also deployed by USGS as part of an ongoing program designed to study currents and sediment transport on the Georges Bank Region in cooperation with WHOI, BLM, and EG&G. An oil spill risk analysis model was run at the Reston, Virginia office of USGS.

The Energy Research and Development Administration (ERDA) through the Division of Environmental Control Technology provided partial funding for oil trajectory modeling under M. Spaulding, chemical analysis of water and sediment samples under C. Brown, and oil droplet size distribution determinations under P. Cornillon, all of the University of Rhode Island, through Contract EY-76-S-02-4047, "Environmental Assessment of Treated Oil Spills vs. Untreated Oil Spills."

The National Science Foundation supported research activities and ship operations at Woods Hole Oceanographic Institution and the University of Rhode Island.

The State of Massachusetts Division of Fisheries and Wildlife instituted a collection and clean-up effort for oil birds.

The University of Rhode Island (URI) conducted four cruises to the oil spill site aboard the R/V *Endeavor*. The first cruise, funded in part by NSF and ERDA, included the deployment of a current meter array; collection and analysis of sediment samples for hydrocarbons; collection and analysis of water samples for hydrocarbons, physical properties, oxygen content, nutrients, and trace metals; and the collection and description of benthic and planktonic organisms. URI's second and third *Endeavor* cruises, funded in part by NOAA, conducted a bottom survey of the Nantucket Shoals-Little George's Bank. The fourth *Endeavor* cruise, funded in part by NOAA, determined the areal extent of the bottom contamination. URI personnel, in an ERDA-funded project, carried out some trajectory forecast modeling, and studied the physical and chemical characteristics of the oil.

Woods Hole Oceanographic Institution (WHOI) conducted two cruises on the R/V *Oceanus II*, sampling both water column and sediments, and characterizing the physical oceanography of the spill site. WHOI participated in a Nantucket littoral zone survey coordinated by NOAA. Scientists from the Marine Biological Laboratory at Woods Hole and the University of Massachusetts joined WHOI in the Nantucket survey. Peter Fricke of WHOI was responsible for procuring oil that was physically and chemically congruent to the *Argo Merchant* cargo for analytical purposes and toxicity studies.

Jerry Milgram of the Massachusetts Institute of Technology collected oil from one of the *Argo Merchant* cargo tanks and from the oil slick and analyzed the physical properties of both samples.

The Manomet Bird Observatory provided data on seabird observations from various locations including the USCGC *Vigilant* on-scene at Fishing Rip.

Individuals who contributed to various aspects of the total research effort include Ron Kolpack of the University of Southern California, who supplied expertise in hydrocarbon-sediment interaction; Ben Baxter, who contributed his knowledge as a trained marine mammal observer; and Barbara Morson, who provided seabird expertise.

References

National Academy of Sciences, 1975. "Petroleum in The Marine Environment," NAS, Washington, D.C. 20418, 107pp.

Keith, V. V., and J. D. Porricelli, 1973. "An Analysis of Oil Outflows due to Tanker Accidents," in Proceedings of Joint Conference on Prevention and Control of Oil Spills," American Petroleum Institute, Washington, D.C. 20006, pp. 3-14.

Gilmore, G. A., D. D. Smith, A. H. Rice, E. H. Shenton, and W. H. Moser, 1970. "Systems Study of Oil Spill Cleanup Procedures," Dillingham Corporation Report, American Petroleum Institute, Washington, D.C. 20006.

Marine Pollution Bulletin, 1973. "Oil Spill in Rhode Island," Vol. 4(6), p. 84 (*Pennant* spill).

North, W. J., 1967. "Tampico: A Study of Destruction and Restoration," Sea Frontiers, 13(8), pp. 212-217.

Forrester, W. D., 1971. "Distribution of Oil Particles Following the Grounding of the Tanker *Arrow*," J. Mar. Res., 29, pp. 151-170.

Strangham, D., 1971. Editor, "Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill 1969-1970," Vol. 1, "Biology and Bacteriology," Allan Hancock Foundation, University of Southern California, Los Angeles, 426 pp.

Kolpack, R. L., 1971. Editor, "Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill 1969-1970," Vol. II, "Physical, Chemical, and Geological Studies," Allan Hancock Foundation, University of Southern California, Los Angeles, 477 pp.

Chan, G. L., 1973. " A Study of the Effects of the San Francisco Oil Spill on Marine Organisms," in Proceedings of Joint Conference on Prevention and Control of Oil Spills, American Petroleum Institute, Washington, D.C. 20006, pp. 741-782.

"Polluting Incidents in and Around U.S. Waters," Calendar Years 1971, 1972, 1973, 1974, and 1975, Commandant (G-WEP), U.S. Coast Guard, Washington, D.C. 20590.

2. INVESTIGATIONS OF PHYSICAL PROCESSES

In order to determine the factors that cause oil spill transport and the rates at which the spill changes physically with time, a series of studies were conducted that combined both modeling and observation of transport processes. The objective of this research is to upgrade models capable of forecasting oil spill trajectories and/or probabilities of shoreline impact under various environmental conditions.

The motion of oil floating on water is determined by three factors: currents, waves, and winds. While the oil is bodily carried by water currents, it is capable of sliding relative to the water in response to the forces of waves and winds. It has been long known that oil placed on the water surface will absorb the smaller and shorter waves by viscous decay and act to calm the seas. Additionally, the irrotational nature of wave motion generates a drift at the water surface (stokes drift), but this irrotational motion does not satisfy boundary conditions at the free surface, and as a result vorticity is generated. In the presence of an oil film, the vorticity generated at the surface quickly propagates vertically through the oil because of its relatively high viscosity and increases the surface speed (Milgram 1977). This increase in speed is considerably larger than the contribution caused by wave absorption. The mechanism by which oil gains velocity is not fully understood, but it is a function of wave length and height, the thickness of the oil, the physical properties of the oil, such as surface tension and visocity, and the physical properties of the oil-water interface. Wind, in addition to being the prime generator of waves, can also act directly on the surface oil, causing a transfer of energy from the wind to the oil.

Although many oil spills have occurred in cold-water environments, instruments have not been adequate to measure these spills and to characterize their behavior and the surrounding environment in sufficient detail to provide all the data required to compare actual spill behavior with trajectory model forecasts. Such characterization requires measurements of environmental conditions, both within and outside the spill, as well as a fixed reference point to which one can relate spill movements.

Throughout the course of the effort connected with the *Argo Merchant*, NOAA and USCG researchers continually compared model-generated forecasts of oil spill trajectories with the observed behavior of oil in the marine environment. These comparisons were required to evaluate the accuracy of the oil spill forecasts at various phases in the program, and to identify those elements of the modeling effort that needed refining and of the observational program that needed strengthening.

2.1 Techniques of Field Efforts

Numerous agencies and institutions participated in studying the physical processes that the oil from the *Argo Merchant* underwent. These included the NOAA-USCG SOR Team, USCG, NASA, EPA, NOAA's Flight Operation Group and Data Buoy Office, and Aero-Marine Surveys, Inc. (a BLM subcontractor), USGS, and

WHOI. Observational platforms included satellites, aircraft, ships and buoys. Each of the participating groups conducted multifaceted operations and used different techniques. These are described in the sections that follow.

2.1.1 Airborne Operations

Observations were made from the Landsat II, NOAA, and GEOS satellites, and from various government aircraft operated by the USCG, NASA, NOAA, as well as private aircraft sponsored by the SOR Team, EPA, and AMSI. Details on these overflights are given in Appendix VI. In general, weather conditions at the site of the wreck were unfavorable for most of these activities. Winds were typically greater than 20 knots and at times in excess of 40. Only on a few days was the cloud base higher than 1000 feet; mostly it was 500 feet or less. To the east of the shoals heavy clouds covered the Continental Shelf and Slope out past the Gulf Stream 90% of the time. Icing conditions severely limited aircraft operations on several days.

Only a few satellite passes provided useful information because of the cloud cover. Also, the resolutions of all satellites, except possibly Landsat, prohibit the actual tracking or mapping of oil. Infrared (IR) imagery from the NOAA and GOES satellites was very limited, and only small portions of the Gulf Stream could be delineated on it.

The USCG supported the SOR Team and other activities by supplying aircraft logistics in HU-16E fixed-wing aircraft and H-3 helicopters. The HU-16E missions were primarily for mapping the extent of the oil, while the H-3 missions were generally aimed at measuring transport processes. All missions were multipurpose.

The USCG mapping effort was coordinated by J. Deaver of the USCG Oceanographic Unit and consisted of a "real-time" description obtained by visual and IR observations, as well as photographic recordings that will eventually refine the real-time effort. In addition to its contribution to the research effort, this real-time work will prove vital to the assessment of any immediate and long-term impacts.

The USCG's first mapping flight was on December 17, 1976, and included two SOR Team members. This flight permitted visual, photographic, and videotape observations of the site of the wreck, current measurements, and two transects of IR sea surface temperature before weather caused termination of the flight. The next day a more extensive survey was conducted which included differential velocity measurements (oil/water), current measurements, sea surface temperature measurements, as well as oil surveillance. At the conclusion of this flight, the Federal-On-Scene Coordinator (OSC) and the SOR Team concluded that continuing real-time reconnaissance was essential to scientific as well as operational goals. Daily mapping operations were conducted until January 5, 1977, except when interrupted by severe weather on December 28 and 29, 1976, and by an engine failure on December 30. Additional mapping flights were flown in January on an irregular basis. Observers on all these flights included both USCG Oceanographic Unit and SOR Team personnel, with the USCG personnel operating all the equipment.

Oil mapping flights were conducted by two observers flying in an HU-16E at 500 feet or below at a speed of 145 knots. Continuous visual contact with the sea surface was maintained from shoreline departure until return. A grid-like search track was used, consisting of station points every 10 miles (or an average of 4.2 minutes) flying time. Loran A, radar, and TACAN were used as navigational aids. Infrared sea surface temperatures were measured by a Barnes PRT-5 radiometer and recorded continuously on an analog strip chart recorder to a precision of 0.1°C and an accuracy of $\pm$ 0.6°C. Visual sightings of oil, size, direction of surface drift, and time of observation were annotated on the IR strip chart trace. The oil sightings were also noted on a plotting chart, which was a duplicate of the navigator's chart. Concentrations of oil were separated by a core and shell limit contours. Percentage of concentration and size were determined by a gridded viewing device, a clear plastic grid divided into 25 squares. This device had an inclinometer attached to the side. When viewing from the aircraft in level flight, the observer could thus determine not only the area of an object on the surface, but also the percentage of surface covered. At fractional surface area coverages of less than 5 to 10%, the visual estimates appear to be high by a factor of 2 to 4, but it is hoped that good NASA or AMSI overflights with photographic coverage will provide a scalar correction factor for these low surface coverages. Also plotted with the oil sightings were surface temperature contour crossings. These strong thermal gradients are indicators of current boundaries, and will aid in the overall analysis.

The H-3 helicopter missions generally were aimed at measuring oil transport processes and collecting oil samples. During these flights, current measurements were acquired with Richardson current probes, while differential oil/water velocities were measured by means of time lapse photography and special range finders to record the separation of oil pancakes and dye markers in the water. Oil samples from the slicks were taken using a small bucket, with the helicopter hovering at 100 feet. Drifting buoys were also deployed on various occasions from these aircraft.

More than 28 operational missions were flown by the USCG for oil mapping and in partial response to scientific requests, accounting for more than 114 hours of air time. The true value of this response to the research effort cannot be estimated, but without USCG logistic support studies of physical processes would have been marginal or nonexistent.

NASA overflights were conducted on December 19 and 22, 1976, and on January 3, 5, and 6, 1977, under the general direction of J. Mugler, Langley Research Center (LRC), NASA. Table VII-1 (in Appendix VII) presents the flight log for the December 19 overflight and Figure 2-1 shows the flight lines. The flight log for the NASA overflight on December 22, 1976, is shown in Table VII-2 and the flight lines are shown in Figure VII-1. The flight logs and flight lines for the NASA overflights on January 3, 5, and 6 are shown in Tables VII-3 to VII-5 and Figures VII-2 to VII-4.

Imagery was obtained from the Landsat II satellite during overpasses near the grounded tanker on December 22 and 23, 1976, and on January 9, 1977. Maps showing the approximate ground coverage expected for these images are presented in Figures VII-5 and VII-6. On December 22, 1976, cloud cover was

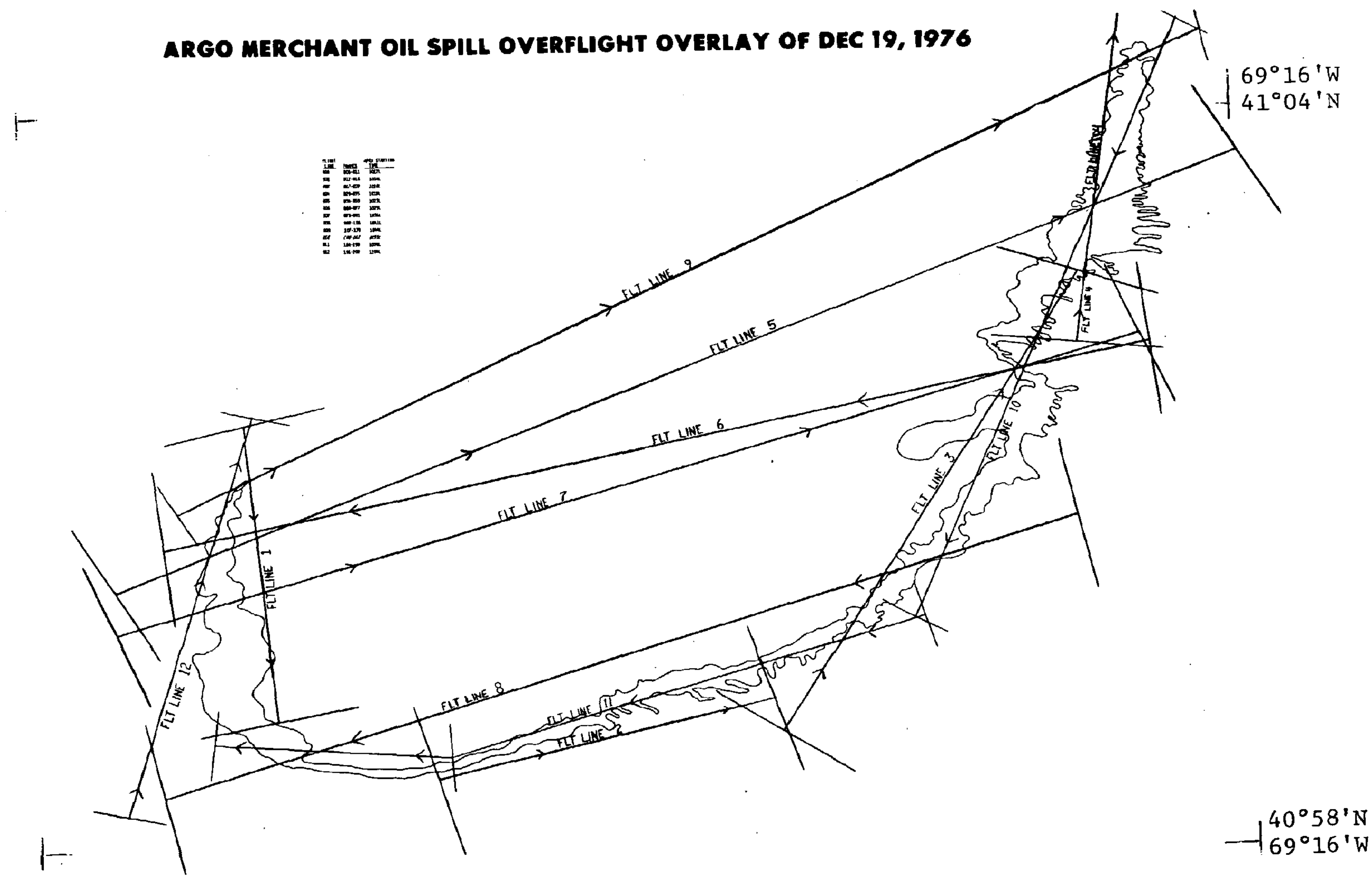


Figure 2-1. Flight lines for NASA flight on December 19, 1976.

about 90% over the region covered by the Landsat imagery, and no useful data could be extracted. On December 23, 1976, cloud cover was about 70 to 80%. There appeared to be several breaks in the cloud cover; however, analysis of the imagery by D. Bowker, LRC, NASA, using digital and density slicing techniques failed to identify oil on the ocean surface. On January 9, 1977, cloud cover was about 20%; again, however, analysis of the imagery failed to show oil on the ocean surface.

EPA sponsored three overflights of the wreck site on December 18, 19, and 22. These flights were conducted by New England Airphoto Associates, Inc., of Shrewsberry, Massachusetts, in a Cessna TU 206. Approximately 300 9- x 9-inch color photographs were taken with a vertical aerial camera. Very few of the photographs on the first flight are usable because of the low ceiling, but 96 photographs were taken on December 19, and 199 on December 22. The last two flight tracks were nearly coincident in time and space with the NASA coverage (Figures 2-1 and VII-1), so both large format color and color IR photographs are available for analysis. The EPA photography can be obtained from EPA, P.O. Box 15027, Las Vegas, Nevada 89114.

A NOAA C-130 conducted two oil mapping flights on January 12 and 13, 1977. These flights were requested by the On-Scene Coordinator (OSC), Captain L. Hein, through personnel of the Marine Ecoystems Analysis (MESA) Program Office because USCG aircraft (HU-16E) were unable to reach the distant area where the oil was thought to be. Both of these flights were funded by the OCS and carried NOAA and USCG personnel to conduct the observations. Both flights located oil southeast of the *Argo Merchant* at distances of more than 100 miles (see maps IV-19 and IV-20, Appendix IV).

Aero-Marine Surveys, Inc. (AMSI) of New London, Connecticut, is the Raytheon Company's subcontractor for Lagrangian tracer studies of the Bureau of Land Management's (BLM) New England Outer Continental Shelf (OCS) Physical Oceanography study. EG&G is also involved in these physical oceanography studies under a separate contract from BLM. The main objective of the Lagrangian investigations is to define the regional, local and fine-grain surface currents of Georges Bank in the context of the transport of oils released in the course of oil production. From a broader view, there is the hope that new knowledge on oil transport will emerge.

The two companies' involvement with the *Argo Merchant* spill began shortly after the vessel ran aground, and by the week's end representatives had arrived in Hyannis, Massachusetts. EG&G made contact with appropriate NOAA and USCG personnel and accompanied members of the SOR Team on reconnaissance flights in chartered aircraft. AMSI positioned a twin-engine marine survey airplane in Hyannis on Wednesday, December 22, after having received authorization from BLM through Raytheon to mount a limited field survey effort in cooperation with EG&G.

Efforts were made to augment the USCG oil mapping work with additional coverage by AMSI. Operational tasks included visual observations, dropping of drift cards, and temperature measurements. The most important measurements may be realized in widely distributed vertical photographs obtained by AMSI portraying the oil "pancakes" in detail. This might permit a correlation between USCG observations by J. Deaver and NASA and EPA imagery, and model outputs.

Current observations were obtained by AMSI by means of dye markers, vertical photography, and a combination of Loran-C and fixed references. These were central to the BLM support, but will also undoubtedly aid in model validation efforts. Results must await return of the color film, and it is anticipated that the data loss will be high because of severe weather conditions, technical difficulties, and the experimental nature of the techniques used.

Sea surface temperature measurements were obtained with a Barnes PRT-5-S IR radiometer (9.5 to 11.5 microns, linear output), which was virtually identical to the one used by USCG. There were technical difficulties on the first several flights, but later data should be quite good ($\pm$ 0.5°C).

Data reduction will be confined to current and sea surface temperature observations.

2.1.2 Ship Operations

Operations to support investigations of physical processes were conducted from ships supported or operated by USCG, the U.S. Geological Survey (USGS), the Woods Hole Oceanographic Institution (WHOI) and by the University of Rhode Island. Cruise descriptions are contained in Appendix V.

USCG had cutters stationed continuously at the wreck site from the day of the grounding, December 15, 1976, until December 31. These vessels, the *Vigilant* and *Bittersweet*, collected hourly surface meteorological data, acquired water samples for chemical analysis, and supported many other activities in response to OSC requests. The USCGC *Evergreen* conducted a sampling cruise to study the fate of the spilled oil and the cutter *Spar* participated in the oil burning tests as well as supporting other research.

The U.S. Geological Survey (USGS) at Woods Hole Massachusetts, chartered the tug *Whitefoot* for implanting current meter moorings as well as acquiring bottom sediment samples, and WHOI sponsored two cruises of the *Oceanus*, which collected water and sediment samples and implanted a current meter mooring. The University of Rhode Island (URI) sponsored four cruises of the *Endeavor*, which also collected water and sediment samples and implanted a current meter mooring.

2.2 Results of Field Efforts

The results of the field efforts are included under six headings: mapping, physical observations, water motion measurements, oil and differential oil/water velocity measurements, water mass observations, and meteorological observations.

2.2.1 Mapping

The mapping of the *Argo Merchant* spill was more extensive than in the case of any previous spill because of the overall concern with the immediate location and potential impact of this particular spill, and because of the SOR Team's goal of gaining information that could be used to improve predictive modeling. The mapping was a coordinated effort involving several techniques (visual, IR, and photographic) and a number of organizations (NOAA, USCG, ADEC, AMSI, NASA, EPA and BLM), with J. Deaver of the USCG Oceanographic Unit being the principal producer of daily oil-slick maps. In addition to the formal imagery, videotapes and photographs of the spill were taken by the USCG and several representatives of the news media. Most of these records have been identified and are being collected, collated, and summarized by the SOR Team. Interpretation of these data and their ultimate use in improving predictive modeling will constitute an important part of the follow-on research effort.

Among the initial results of the mapping effort was the description of the formation and movement of large "pancakes" (large, thick oil slicks), which maintain their cohesiveness and integrity for long periods of time. There has been considerable interest in the motion and dispersion of such pancakes. Experience gained in an earlier spill in the Florida Keys indicated that they are up to 6 inches thick and that the volume of oil on the surface can be quite substantial. When several pancakes 50 to 90 feet in diameter were spotted on the 5th day of the *Argo Merchant* spill, an effort was begun to describe this phenomenon more fully and to parameterize the process for modeling purposes. On Christmas Day, a 450-foot by 760-foot pancake, estimated to contain the order of 1/2 million gallons of oil, was found (Appendix III, Photographs 37 and 38). On December 31, NOAA and USCG placed a satellite-tracked buoy on this pancake, and the buoy's position is being constantly tracked by NASA Goddard Space Flight Center via the Nimbus-F satellite (see Section 2.2.3).

Oil-slick maps of good quality were obtained on most flights in spite of bad weather (Figure 2-2). Good IR data were obtained less often because of technical problems. The complete set of available maps, up to January 7, 1977, are contained in Appendix IV. These maps are tracings by K. Kidwell of EDS, NOAA, of the flight maps prepared on the scene by J. Deaver of the USCG Oceanographic Unit on oil survey flights for the Federal On-Scene Coordinator's operational use. They show actual oil sightings, and include an interpretation of oil distribution based on the flight tracks. All maps to date show the flight tracks; the extent, nature, and concentration of oil; and, when available, surface temperature data. Oil is presented at approximately three contour levels: (1) threshold - light; (2) light - moderate; and (3) moderate - heavy.

Spot estimates of percentage of surface area covered by oil pancakes are also given. These numbers are derived from visual observations and, as indicated above, are only rough estimates and tend to be somewhat high (possibly by a factor of 2 to 10). Included also are estimates of the size of pancakes, marine mammal sightings (see Section 4.3, and Photograph 28, Appendix III) and miscellaneous notes. Sea surface temperatures are depicted,

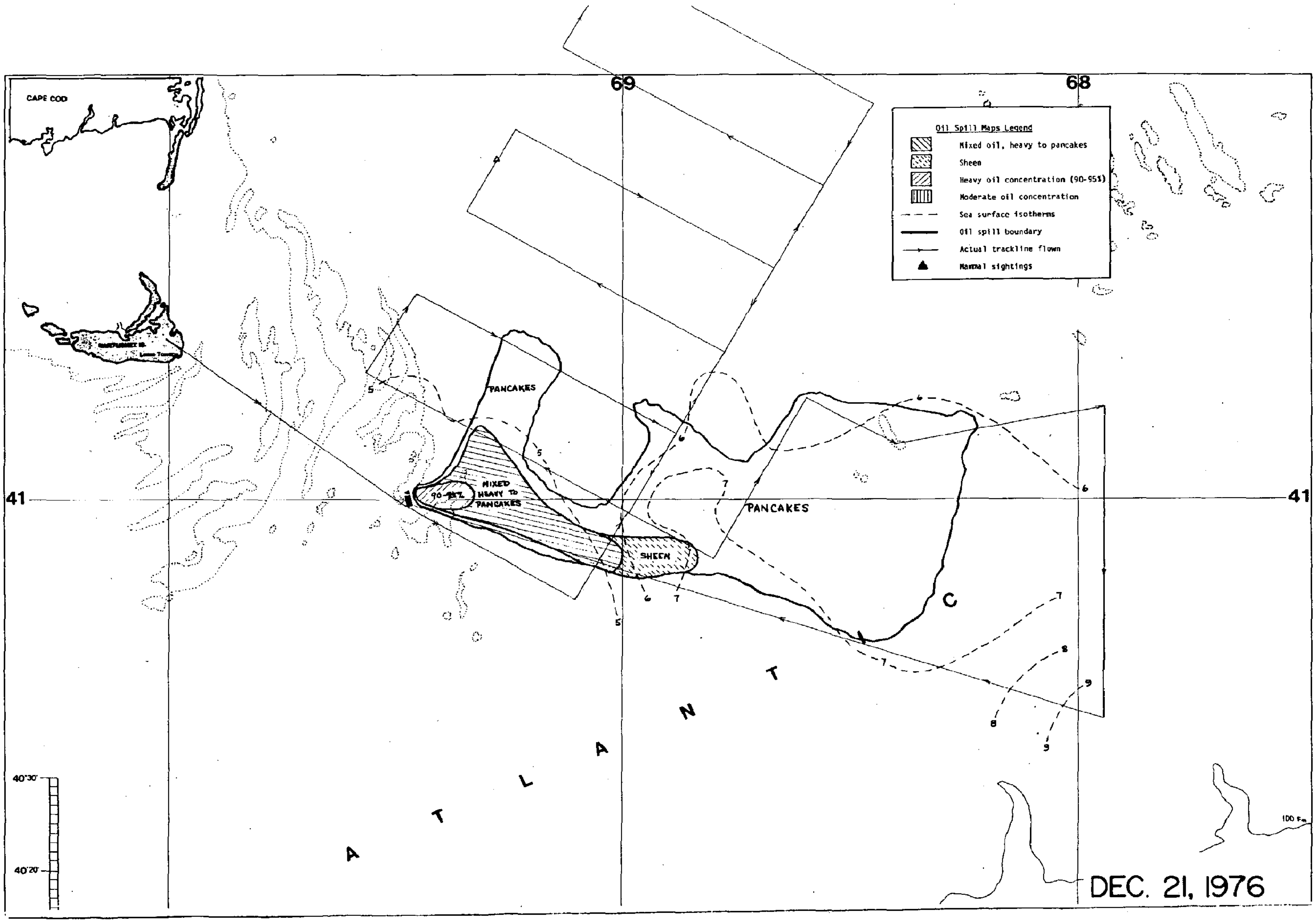


Figure 2-2. Example of oil slick map.

where available, by 1°C contours. Geographic accuracy is that of Loran-A. Strip charts, flight charts, logs, and other original material are being archived by NOAA's Environmental Data Service.

Three conclusions are evident from the oil slick maps. First, the oil distribution was primarily influenced by the clockwise rotary tidal currents and the local winds up until December 21, 1976 as evidenced by the hook pattern on maps IV-1 to IV-5 in Appendix IV. Second, the movement of the oil was offshore to the east-southeast. The speed of the oil was approximately 1.6 knots on December 20-21, and 1.4 knots on December 21-22 under the influence of mean west winds of 30 knots. Third, the oil was not observed north of 41° 21' (map IV-5 in Appendix IV) northwest of 70° 10' (map IV-17 in Appendix IV). Furthermore, the slick was not observed closer than 15 miles off shore of Nantucket (map IV-17 in Appendix IV).

2.2.2 Physical Observations

During the course of the oil spill visual and photographic observations were made of the behavior of the No. 6 fuel in cold water. These observations were made to answer the following questions:

1. What is the life cycle of oil pancakes?

2. How does the oil pick up motion from wind or waves?

3. What are the dynamics of the underside of oil slicks?

4. How does oil get accommodated into the water column?

Few immediate answers were found to these questions, although more data than ever before was collected. Over the next few months, these data will be more carefully analyzed to provide a better understanding of oil behavior in cold water. The data and findings to date are described below.

The SOR Team collected more than 800 photographs during the period covered by this report. A selected group has been included in Appendix III. These photographs show (1) the history of the oil discharge from the *Argo Merchant* (Photographs 1 to 16); (2) details of oil distribution and pancake formation and life cycle (Photographs 17 to 28 and 37 to 42); (3) details of oil behavior and bottom side morphology (Photographs 29 to 32); (4) techniques of measuring water and differential oil/water velocities (Photographs 33 to 36); (5) burn tests (Photographs 42 to 44), oil sampling (Photographs 45 and 46), and local fauna (Photographs 47 and 48). Aerial photographs were taken to calibrate visual estimates of the areal extent of pancakes and sheen in oiled areas. Vertical aerial photography was obtained on NASA, AMSI, and EPA overflights. Of particular interest in describing the behavior of the oil are the NASA flights on December 19 and 22.

The NASA overflight on December 19 yielded 202 infrared 9" x 9" color photographs along the flight track shown in Figure 2-1. Twelve legs were flown over a period of 1 hour and 52 minutes (Table VII-1). Five frames were selected and printed to show typical results (Photographs 17 through 21,

Appendix III). A strip mosaic of data from the December 19 overflight was constructed by the Air Force 9th Tactical Intelligence Squadron, Langley Air Force Base, Virginia (Photograph 22). The location and geometry of the plume can be seen faintly in this strip mosaic.

Additional photographs superimposed on the strip mosaic in Photograph 22 are shown in strip mosaic form in Photograph 23, which therefore represents all the imagery obtained during the December 19 overflight and may be useful for more detailed studies of the plume characteristics. On several of the flight lines photographs of the slick were obtained, with time separations that provide quantitative information on the motions of the oil in this region. Photographs 19 and 20 are of the same area separated by about 9 minutes. Photograph 19 was taken at 10:29:03; its nadir point is 41° 0.2 N, 69° 20.3 W, and the vertical edge is 5°. Photograph 20 was taken 9 minutes later at 10:37:47. Its nadir point was 41° 01.8 N, 69° 19.8 W, or 3300 feet away in a direction of 136°. The orientation of this photograph is 348°. The width of the photo is approximately 7850 feet. These two photographs indicate that the oil slick rotated 5° counterclockwise in a region of current shear and moved about 0.44 mile to the southeast. Also indicated are the development of stringers at almost right angles to the direction of the wind (250°). It should be noted that the coordinates given to NASA for the location of the *Argo Merchant* on December 19 were not correct. They were given as 40° 01' N, 69° 28.5' W, but the actual coordinates were 40° 02' N, 69° 24.5' W. Thus, the grid labeling on the mosaics is incorrect by 1 minute in both latitude and longitude.

Coverage from the NASA overflight on December 22 is shown in Figure VII-1, which also gives the approximate locations of five frames taken during that flight. Typical examples of the photographs obtained are shown in Photographs 24 to 28 (Appendix III). Data from the flights on December 22 and January 3, 5, and 6 are being printed and reviewed.

On December 21, the SOR Team requested support from the U. S. Navy to supply a diving team to examine the underside of the oil slick from the *Argo Merchant*. Four divers from the Atlantic Fleet Audio Visual Command responded to the request and were on the scene on December 23. During the dive they acquired 200 feet of 16-millimeter color movie footage, as well as numerous still phtographs. The following debriefing describes their findings.

The four Navy divers were transported by a USCG helicopter to the *Vigilant* at 0830 AM on December 23, 1976. By 1030, two divers were in the water. Both had trouble descending because of the cold water, 5 to 6°C (41 to 43°F). The cutter had given them a depth indication of 48 feet, but to their surprise the bottom was at 140 feet. The precise location of the divers is not known, but they were directly under the path of the oil slick, which was headed northeast from the *Argo Merchant*. The visibility was 10 to 20 feet. The divers hit bottom and tried to get good visual coverage. The bottom was clean white sand, covered with clams. The divers made a complete circle without spending too much time on the bottom. They filmed and observed a 10- to 15-foot square area and found no visual traces of oil. (The oil slick had passed over the area they observed because of tides twice a day for 7 days.) When the divers came back up, the oil looked like "burned carbon" and also appeared corrugated (from wave action). The oil behaved "like mercury." A bubble of air would come up and move the oil out of a circle; wave action might keep it apart for a while, but it would then come back together (Photograph 20, Appendix III). The general area of the slick was sheen oil. Within that sheen, there were several pancakes. No oil extended beneath the pancakes and the bottoms of the pancakes were flat, similar to the tops. The thickness of the oil above the heads of the divers was 1½ to 2 inches. similar to what the SOR Team observed on Sunday, December 19, at the end of 18 miles of slick. The photo-graphed pancake was 8 to 10 feet wide and 30 feet long. Its edges were well defined and no feathering was observed (Photograph 30). The current was no more than 3/4 knots. In order to observe the water motion directly under the slick, the divers released dye into the water. Some of the dye moved with, some behind, and some ahead of the oil (Photograph 31). They saw one dye streamer sitting on the underside of the pancake and staying with it. This is documented in the movie coverage. When taking pictures of one certain glob of oil, the divers were 10 to 15 feet from it. There seemed to be a lot of dye in one area. The oil was moving back and away, and the dye was coming forward. A very light breeze was blowing on the surface. The only time the divers experienced a stinging sensation from the oil was when they were cleaning up. They found the best cleanser to be "Edge" shaving cream.

During the many sightings of large pancakes of oil on mapping flights, it was observed that oil sheen was generally upwind of the pancakes (Photographs 37 and 44, in Appendix III). This implies that the sheen is fed from the pancakes and moves at a slightly slower velocity, consistent with the concept that the differentical oil/water velocity is somehow proportional to oil thickness.

The following estimates of the thickness of the oil slick and pancakes were acquired:

Date	Location	Age (days)	Thickness (inches)	Comments
12/19/76	End of slick	2-3	2	Visual during SOR sampling
12/23/76	Slick near *Argo Merchant*	1-2	1.5-2	Divers - visual estimate
12/25/76	Pancake #1	5-8	4-6	Estimated from the *Vigilant*
12/31/76	Pancake	8-13	6-10	Estimated from the *Spar*

While it is true that these measurements were not made on the same parcel of oil, it appears that the pancakes consolidated and got thicker as they aged.

2.2.3 Water Motion Measurements

Both Eulerian (at a point) and Lagrangian (following a parcel) water motion measurements were obtained in the vicinity of the *Argo Merchant* and the oil released from it. In addition some historical data have been uncovered and are available. It should be noted that in the immediate area of the wreck there are strong tidal currents, which at times exceed 2 knots. One measurement indicated approximately 6 knots. These currents are strongly influenced by local topography, and extrapolation may be very difficult if not impossible. Table VII-6 in Appendix VII contains tide predictions from the National Ocean Survey (NOS), NOAA.

Eulerian water motion measurements were obtained by standard current meter techniques as well as by current probes deployable from the air. In response to the oil spill, six moorings for measuring water currents were implanted. B. Butman, USGS, Massachusetts, implanted four current meter moorings from the tug *Whitefoot*. Three of these moorings contained one or more self-recording current meters, while the fourth (121) was a tripod mooring that recorded sediment conditions, currents, water depths, light transmission, and bottom photographs every four hours. A current meter mooring was also implanted at the Nantucket Light Ship during Cruise 20 of the *Oceanus* on December 28. Before the oil spill on December 5, B. Butman and D. Folger, USGS, had implanted a current meter mooring in the area from the *Oceanus*. The *Endeavor* implanted a current meter mooring supplied by D. Shonting of the Underwater Systems Center (NUSC) on December 29, 1976. An attempt to recover this mooring on February 9, 1977, was unsuccessful because it could not be relocated. Attempts to relocate this mooring are continuing. All these moorings were to be retrieved during February or March 1977, and the data obtained will be available through EDS, NOAA. In the historical past, NOS has measured currents to support tidal table generation in the area where the *Argo Merchant* foundered. These records are of short duration and are available through EDS. Three sites were covered in 1960 and three others in 1932. Table VII-7 gives the characteristics of all current moorings, and Figure 2-3 shows their locations.

In response to the spill, single-point measurements were obtained by the SOR Team and by AMSI with Richardson current probes (Photographs 33 and 34, Appendix III) deployed from the air. These current probes operate by releasing packets of dye at known time intervals after they are resting on the bottom. The packets rise to the surface whency they are carried by the surface currents. By assuming that they follow the same path from the bottom to the surface (i.e., the vertical current structure is constant), then the separation of the dye packets when they are both on the surface is only a function of the surface current velocity and the known time interval between releases. Table 2-1 gives the results of these measurements, most of which were taken in support of oil and oil/water differential velocity studies (see Section 2.2.4).

Lagrangian water motion measurements were obtained by tracking, as a function of time, USCG datum marker buoys (DMBs), large sheets of plywood, large dye patches, drift cards, sea bed drifters, and a NOAA drifting buoy.

DMBs are generally used by USCG for search and rescue missions. They are tracked by a radio beacon and have an operational life of 36 hours. Since these buoys do not transmit a unique identifier, there may be confusion if many are deployed in the same region. Five DMBs were deployed, as indicated in Table VII-8 in Appendix VII, and tracked. The first was tracked from 1048 on December 18 until 1023 on December 20, showing four positions.

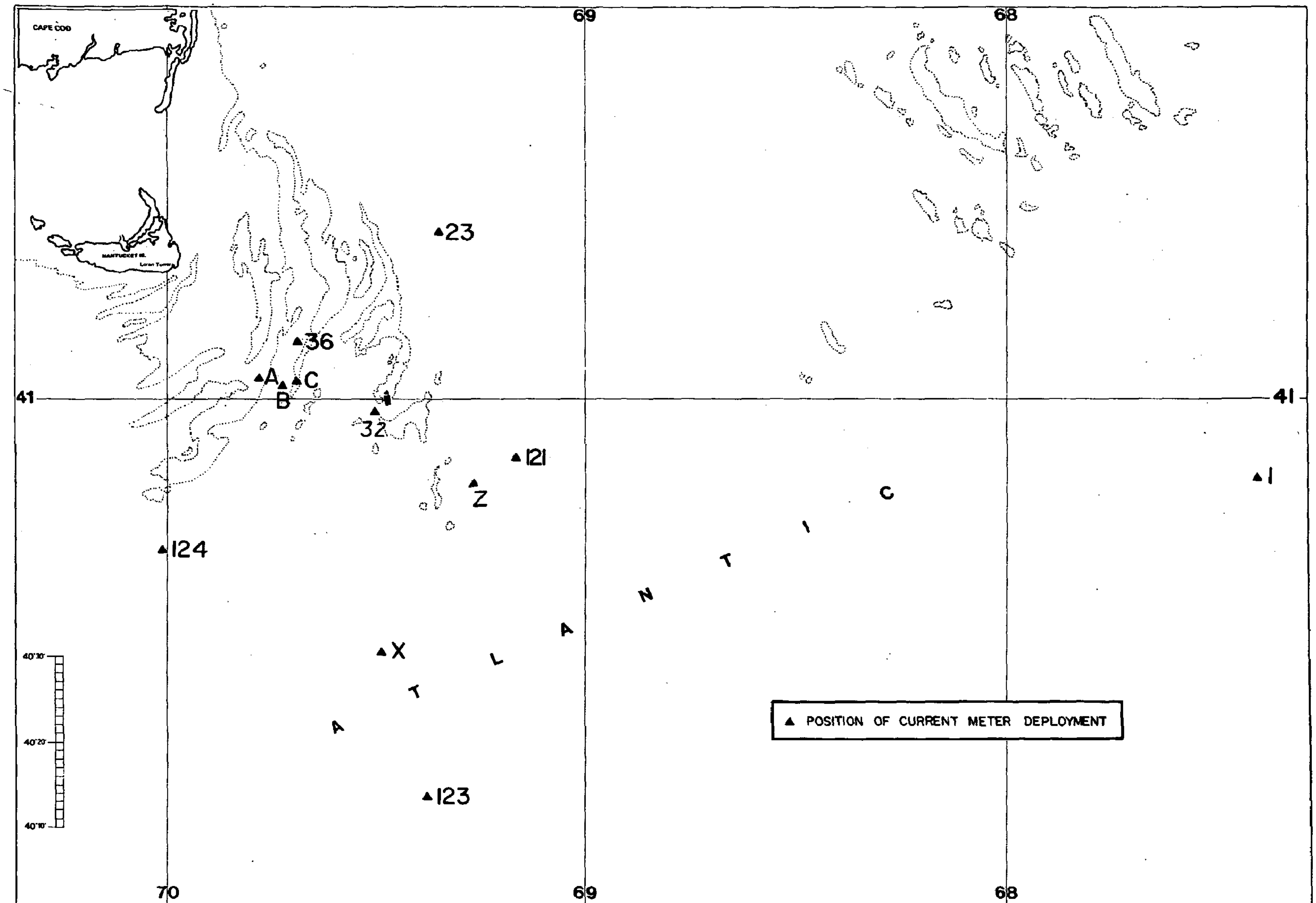

CAPE COD
NANTUCKET ISL.
69
68
41
70
▲23
▲36
▲A
▲B
▲C
▲32
▲121
▲Z
▲124
▲X
▲123
▲1
A T L A N T I C
▲ POSITION OF CURRENT METER DEPLOYMENT
40°30'
40°20'
40°10'

Table 2-1. Summary of current measurements with Richardson probes deployed from aircraft

Date	Time	Wind (kt)	Wind (°true)	Current (kt)	Current (°true)	Location relative to *Argo Merchant*	Observer
12/16/76	1040	16	56	1.7	270	300 yd W	Chan/Hufford
12/17/76	1200	16	270	1.4	315	200 yd SE	Grose/Hufford
12/17/76	1300	18	290	1.2	315	300 yd NW	Grose/Hufford
12/19/76	1300	18	240	1.6		7.5 mi ENE	Mattson/Galt
12/20/76	1130	15	195	0.2	30	300 yd E	Mattson/Kennedy
12/21/76	1610	35	240	0.6	270	1/2 mi S	Galt/Lease
1/4/77	1030	5	060	0.9	180	within 1/2 mi	Galt/Kennedy
1/4/77	1200	5	0600	1.6	?	between Bow and Stern	Galt/Kennedy

The second DMB was launched at 1020 on December 27 and was believed to be spotted on December 31 at approximately noon after traveling 21.5 nautical miles in a direction of 135° (0.22 knots). The third DMB was deployed in a large pancake on December 31 at 1340, and the NOAA drifting buoy was dropped in this same pancake at 1630. Unfortunately, a good position indication was not obtained because of instrument problems at 1630, but the buoy position at 2217 is known.

Sheets of plywood (4 feet x 8 feet) were deployed from USCG cutters into the oil slick on four occasions, as indicated in Table VII-8. Only one of these drifters was ever relocated.

Drift cards were dropped from aircraft on several occasions for two purposes. The most important one was to serve as an early warning system when east or southeast winds threatened to blow the oil ashore. Each of these releases consisted of 1000 cards, and their positions and times are noted in Table VII-9 and Figure 2-4. Fortunately, the east winds were not sustained, and no drift cards have been recovered from shore. The second reason for using drift cards was to mark particular areas of oil for visual reference during transport studies. These deployments were generally made in batches of 25 cards. However, 100 were deployed on December 26 on top of the large "pancake 1," and positively identified this pancake when it was re-spotted on December 27. On the NOAA C-130 flight on January 12, 1977, drift cards were observed in oil at 38° 45'N, from 65 to 66°W, confirming that this oil was from the *Argo Merchant*.

In order to help predict the course of the oil slick, it was decided during the evening of December 28 to try and deploy a trackable buoy into a pancake of oil as soon as possible. A NOAA drifting buoy that communicates its position through the Nimbus-F satellite was chosen to be the candidate buoy. The NOAA Data Buoy Office, Bay St. Louis, Mississippi, responded to the request and arranged for two buoys to be delivered to Hyannis, Massachusetts. One buoy (ID #343) was borrowed from Nova University and was delivered on December 30. A backup buoy (ID #567) was delivered from the manufacturer in Los Angeles, California, on January 1, 1977. This buoy was never used. Buoy 343 was dropped by the SOR Team from a USCG H-3 helicopter at 1630 on December 31, 1976. It was placed in the center of a large pancake of oil (75 feet x 35 feet) in the hope that it would stay with the oil and generate positions independent of weather both to guide aircraft reconnaissance flights and to actually track the oil. There were some deployment problems as the quick release would not activate and the hoist cable had to be cut at the winch. Only visual observations were made at time of deployment because it was dark and only the hover flood lights were available to illuminate the oil pancake. Subsequently, the buoy, the launch sling, and the cable were observed in the oil, as well as lumber and other flotsam. For the next 8 days, reports on positions were received at Hyannis via special arrangement from Nimbus-F control at NASA Goddard Space Flight Center. This tracking of the oil was highly successful, in spite of intervening bad weather, which prohibited flights. On January 2, 3, 12, and 13, the oil was relocated and mapped using buoy positions as an aid. Table VII-10 in Appendix VII lists the positions and velocities of the buoy as determined by Nimbus-F up to the time of this report. Figure 2-5 shows the track of the buoy.

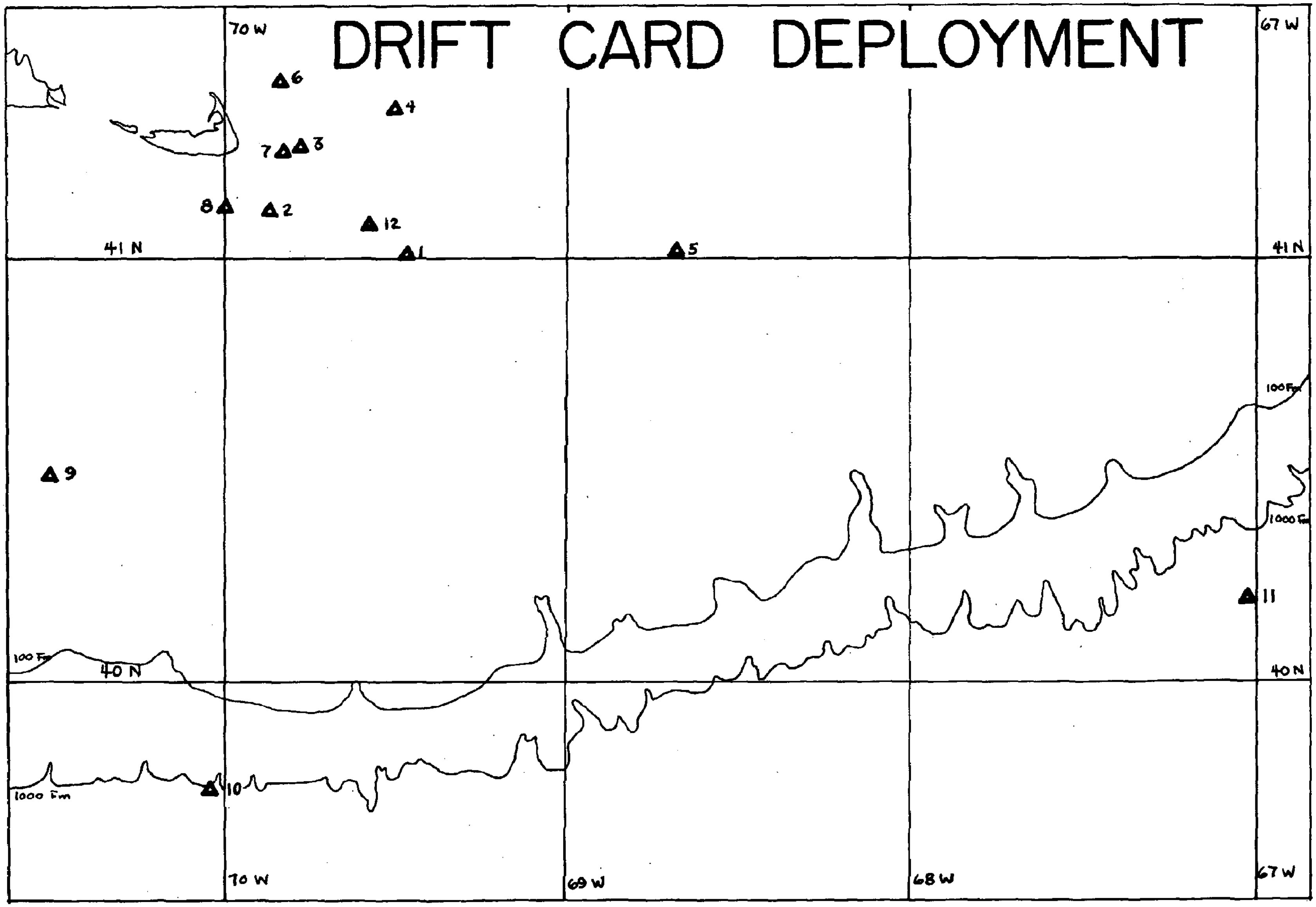


Figure 2-4. Locations of drift card deployments (refer to Table VII-9, Appendix VII).

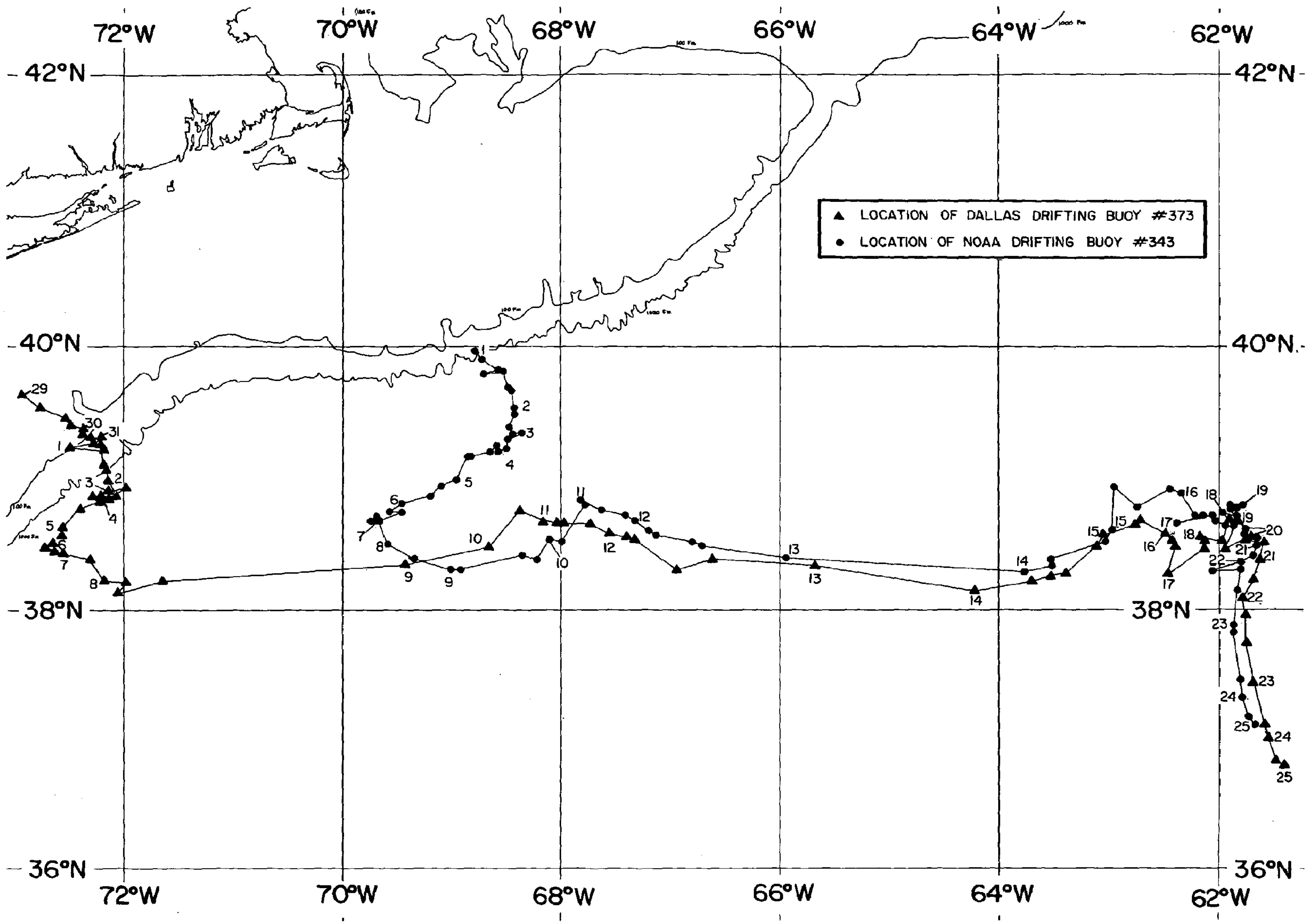


Figure 2-5. Track lines of drifting buoys (refer to Tables VII-10 and VII-11, Appendix VII).

A second buoy (ID #0373) was deployed by the USCGC *Dallas* as part of a separate experiment on December 27, 1976. This experiment was conducted jointly by NOAA (NDBO and the Atlantic Oceanographic and Meteorological Laboratories) and USCG as part of the New York Bight MESA program. This buoy had a drogue attached to couple the buoy's motion to the water at 400 meters. Since deployment, however, the drogue monitoring sensor has indicated that the drogue is not attached or that the sensor has malfunctioned. Table VII-11 contains the positions and velocities of this buoy, and Figure 2-5 indicates its track up to the time of this report.

In a joint project by NMFS (Woods Hole) and URI's Coastal Resources Center seabed drifters were released in an attempt to measure bottom currents at Nantucket Shoals and Georges Bank. Seven releases of 150 drifters each were made on January 6, 1977, to the west of the wreck site from a USCG helicopter. Five drifters were also released at each station (except No. 27) occupied by the second *Delaware II* cruise in January. An additional 150 drifters were also released on URI *Endeavor* cruise EN-005 at the wreck site and at the leading edge of sediment contamination. To date, six seabed drifters have been recovered according to C. Griscom of URI. The locations of recovery are indicated in Table 2-2.

2.2.4 Oil Velocity

Oil velocity measurements were acquired both relative to fixed references over short time periods and by navigational fixes on individual oil pancakes over periods of hours during USCG mapping flights. On December 31 at 1340 a pancake was marked by a datum marker buoy at 40°16'N, 66°56'W, and at 1630 a NOAA drifting buoy was inserted into the same pancake. The latter is assumed to have been locked into the oil for the first few days and is being tracked twice daily by Nimbus-F at noon and midnight (see Section 2.2.3). The first five values contained in Table VII-10 probably represent oil velocities.

Differential velocities of oil and surface water were measured by the SOR Team on helicopter and fixed-wing aircraft flights. Dye patches were used to mark the surface water, and the separation and direction of oil and water were then measured as a function of time. These data are primarily contained in photographs and tape recordings. The following summarizes two of the best sets of such measurements, based on both photographic data reduction and visual observations made from a hovering helicopter, with a USCG-developed viewfinder used for distance measurements.

The first set was obtained on December 19, 1976. During this flight, at about 1100 EST, J. Galt and J. Mattson of the SOR Team released three dye "pills" in a line downwind and ahead of the patch. The oil pancake was at the far end of the horseshoe-shaped slick, 18 nautical miles long, emanating from the *Argo Merchant* (Photograph 22, Appendix III). Using time-lapse photography, and knowing the altitude of the aircraft and the acceptance angle of the camera lens, the differential oil/water velocity can be measured directly. The table below summarizes the time-lapse photographs, which were taken at an altitude of 500 feet with a 55-mm lens. Parentheses indicate photographs taken at a lower altitude, for which distances were corrected.

Table 2-2. Seabed drifter returns as of February 5, 1977

Release station	Date	Location Lat. N Long. W (deg / min)	Pickup date	Location Lat. N Long. W (deg / min)	Time (days)	Distance (km)	Direction (°true)
URI 4**	1/6/77	41 10 70 37	1/16/77*	41 06 70 47.5	10	9	244
URI 3	1/6/77	41 03 70 49	1/23/77*	41 02 70 38	17	8	263
URI 3	1/6/77	41 03 70 49	1/23/77*	41 02 70 38	17	8	263
URI 3	1/6/77	41 03 70 49	1/23/77*	41 02 70 38	17	8	263
URI 3	1/6/77	41 03 70 49	1/23/77*	41 02 70 38	17	8	263
NMFS 1	1/4/77	42 07 70 13	1/26/77	Nauset Beach	22	22	140

*Trawled by fishing vessel *Pocahontas*

**Appeared to have an oil droplet on edge. Gas chromatographic analysis by J. Quinn indicates droplet was not *Argo Merchant* oil.

Sequence No.	Photo I.D.	Oil-left Pill	Distance (feet) Left-center pill	Left-right pill	Time (seconds)
0	7/12	42	89	183	0
1	7/13	40	93	171	10
2	7/14	(24)	(91)	(178)	97
3	7/15	24	101	-	100
4	7/16	3	85	165	214

Combining sequence Nos. 4 and 0 (Photographs 35 and 36, Appendix III), produces a differential velocity of 0.11 knot. Sequence Nos. 2 and 0 also yield a differential velocity of 0.11 knot directly downwind. Sequence Nos. 1 and 3 are too close in time to 0 and 2 to give additional differential velocity values, but are indicative of the precision of the method, i.e., about ±10%. Since the USCGC *Vigilant* recorded a wind speed of 10 knots from 250° at 1100 on December 19, the differential velocity obtained in this measurement equates to 1.1% (± 0.1%) of the wind speed. Simultaneously with the above differential velocity experiment, a Richardson current probe was deployed in the same area. Two photographs of this probe give a mean surface current velocity of 1.6 knots (±5 to 10%). Visual observation of the current probe yielded an estimated separation distance of 200 feet, while the two photographs yielded 186 feet and 206 feet respectively. The current direction was estimated to be 205° using wind wave directions as reference.

The second set of measurements was obtained on December 20, when the helicopter hovered over a series of five dye pills at altitudes of 500 to 1500 feet for 20 minutes. Using visual distance measurements with the USCG viewfinder, J. Mattson and D. Kennedy of the SOR Team measured the speed with which a pancake overtook a dye marker. In this instance, the speed was about 0.20 knots. The *Vigilant* reported winds of 17 knots headed 015° at the time (1200 EST, December 20), which yields another differential oil/water velocity of 1.1 to 1.2% of the wind speed. A Richardson current probe deployed at that time yielded a surface current of 1.3 knots at 030°, about 15° to the right of the wind.

Additional differential velocity measurements were made on December 19 at 1245 from a fixed-wing aircraft, and on December 22, 1976, from a USCG helicopter. A summary of all differential velocity measurements is contained in Table 2-3.

2.2.5 Water Mass Measurements

Expendable bathythermographs (XBTs) were taken during several of the cruises conducted in response to the oil spill. The locations are shown in Figure VII-7 in appendix VII. Eleven were obtained from the first *Delaware II* cruise on December 22 and 23, while 43 were obtained from the second *Delaware II* cruise on January 4. Eighty-three XBT stations (not plotted) were taken during cruise 17 of the *Oceanus* (December 3-9, 1976) and 15 XBTs were acquired during *Oceanus* cruise 20 (every station except 13).

Table 2-3. Summary of differential oil/water velocity measurements

Date Time	Wind Speed (kt)	Wind Dir. (°)	Differential velocity Speed % wind	Differential velocity Direction relative to wind	Measured by
12/19/76 1100	10	250	1.1	0°	Galt Mattson
12/19/76 1200	16	243	0.7*	0°	Chan Grose
12/20/76 1200	17	015	1.1	30°**	Kennedy
12/22/76	30	275	0.8	0°	Chan

* Large uncertainties because of large oblique angles.
** 0° Relative to waves.

R. Wright, NMFS, analyzed the water temperatures acquired during the second *Delaware II* cruise and found them very similar to the average values shown by Colton and Stoddard (1972, charts 1940 to 1959). Temperatures were nearly isothermal, surface to bottom, except in the deeper stations along the southern edge of Georges Bank. Bottom values were usually a few tenths of a degree warmer than those at the surface. The coldest values (less than 5°C) were in water close to shore, with temperatures as low as 2°C at the two shallowest positions south of Nantucket and Martha's Vineyard. Over Georges Bank the range was 5 to 6°C, with water warmer than 6°C in the vicinity of Great South Channel and the extreme southern edge of the Bank. Subsurface values warmer than 10°C, indicative of Slope water, were found at Stations 21 and 23 in deeper water south of the Bank. Otherwise the temperatures were all typical of the shelf water of the region in January. An analysis of the stations from the *Oceanus* cruises in December shows identical results to those obtained from the *Delaware II* data. The surface isotherms indicated on the oil slick maps in Appendix IV also support these conclusions.

Seven XBTs were also taken from the USCGC *Dallas* on December 30 in a line 135 miles long oriented 70° 100 miles to the south, east of the *Argo Merchant*. Figure 2-6 shows this temperature depth section, which indicates a warm core eddy 100 miles south-southeast of the site of the wreck.

2.2.6 Meteorological Observations and Forecasts

Both routine and special surface meteorological data were collected at the site of the *Argo Merchant* and in the surrounding area by USCG, and by FAA at Nantucket Island. In addition to its normal marine forecasts, the National Weather Services in the Boston area supplied special forecasts for the wreck site.

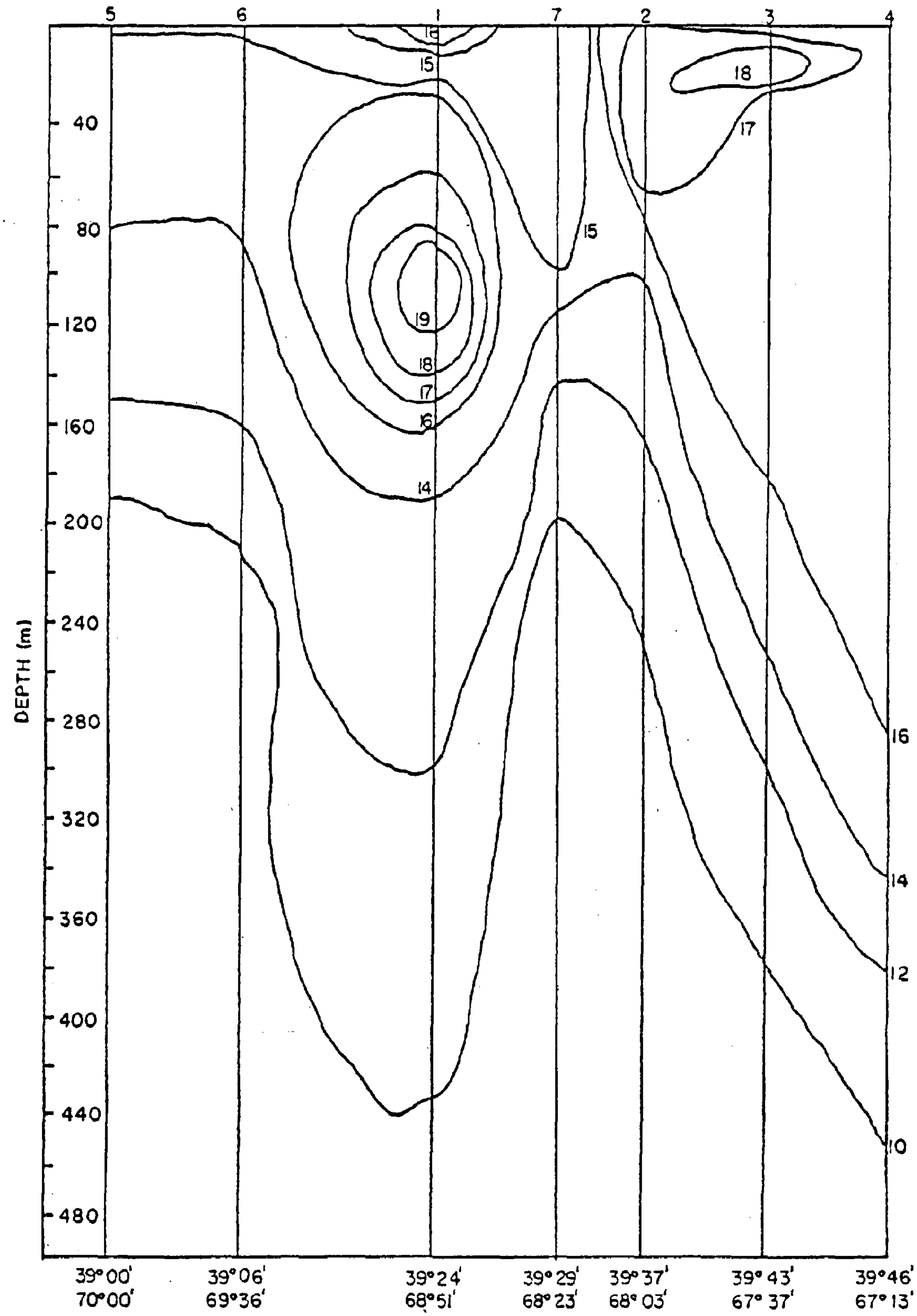


Figure 2-6. XBT section from USCGC *Dallas* on December 30, 1976.

Hourly surface meteorological data were collected at the site of the wreck by the USCGC's *Vigilant* and *Bittersweet* from December 15 through December 31, 1976. Wind speeds and directions were extracted from these data and are contained in Table VII-12 in Appendix VII. Hourly surface data were also collected by the FAA tower at Nantucket Island airport during their operating hours (0600 to 2300) and the resulting wind speeds and directions are summarized in Table VII-13 for this same time period. Similar wind speed and direction data acquired from the Nantucket Light Ship operated by USCG are given in Table VII-14. Data from the Nantucket Island airport and Light Ship for other time periods are available from the National Climatic Center (NCC), Asheville, North Carolina, as a standard archive product.

F. Godshall of NOAA's Center for Experiment Design and Data Analysis did a comparative study of the winds observed at the site of the *Argo Merchant* and those routinely measured at the Nantucket Light Ship. He used a least square vector difference technique (Godshall, et al., 1976), by which an additive direction correction and a wind speed factor was developed based on vector differences that can be used for extrapolation. His findings indicate that over the 15 days of data (Tables VII-12 and VII-14, appendix VII) winds at the *Argo Merchant* site can best be estimated by subtracting 13° from the directions reported by the Light Ship and multiplying the reported speeds by a factor of 1.17.

Meteorological data were acquired on all cruises in the area and, where available, are given in the cruise reports contained in Appendix V.

Using the radar altimeter aboard the Geodynamics Experimental Ocean Satellite, GEOS-3, C. Parsons of Wallops Flight Center, NASA, measured significant wave height in meters in the vicinity of the *Argo Merchant* oil spill from December 24 to 28. The normal scheduling of the satellite was interrupted to accommodate the data collection along 13 ground tracks off the east coast of the United States. These data were processed at the NASA Goddard Space Flight Center to produce significant wave height measurements spaced 3.28 seconds apart in time, an increment designated as the GEOS-3 data frame.

Figure 2-7 shows the positioning of the tracks closest to the oil spill for each of the 5 days. The frame number (in italics) and significant wave height are noted at regular intervals along each track. The latter given quantity is the result of averaging over seven frames, a process that is needed to correct for the inherent noisiness of the GEOS-3 measurement. Because of the rapidity with which the storm systems moved through the area during the December 24-28 period and the separation between consecutive GEOS-3 ground tracks, it was not possible to generate contour maps of significant wave height.

The ground track for orbit 8832 crossed the oil spill on December 24 during frames 114 and 115. The variation of significant wave height near the spill is shown in Figure VII-8 (appendix VII). The dashed line is the variation of the three-frame average. This was used to eliminate some of the noisiness of the measurement without losing all of its spatial resolution. It can be seen that sea state in the vicinity of the spill was of the order 2.5 to 3 meters on December 24. Compared with 2 to 3 feet as observed by the

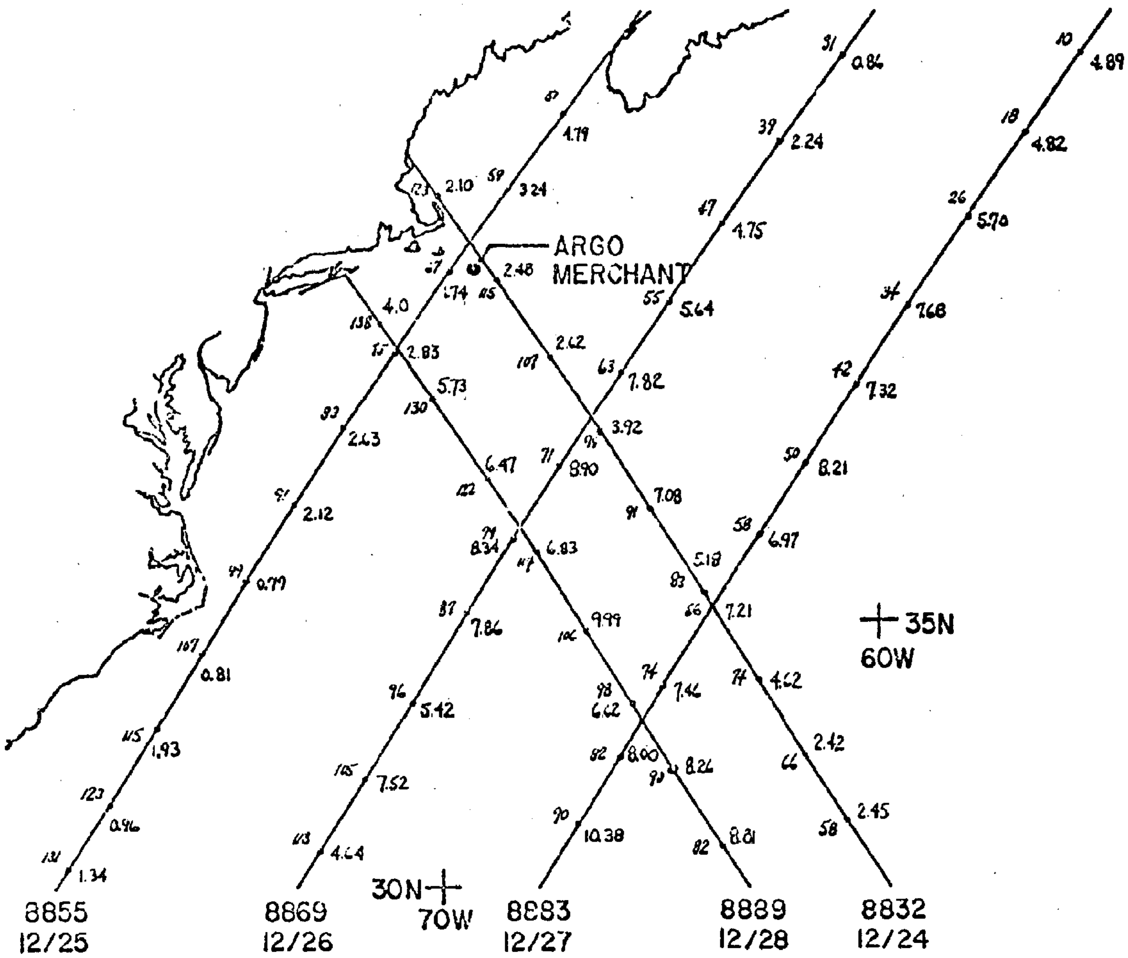


Figure 2-7. GEOS-3 ground tracks for December 24-28, 1976.

Vigilant, this results in a factor of 3 overestimation. Using this as a calibration factor, the wave estimates made from GEOS may possibly be of use as inputs for future modeling efforts.

As part of the National Oil Pollution Contingency Plan Response, the National Weather Service (NWS), NOAA, supplied the Federal On-Scene Coordinator with special marine forecasts for the site of the wreck of the *Argo Merchant* since the day of the grounding. Routine scheduling of the special forecasts began late on December 15. The schedule has varied from as many as six per day to as few as two per day, dependent upon need. Since the initial request for forecast assistance, 252 forecasts have been provided up to February 1, including 147 special forecasts and 103 special wind forecasts.

Some operational problems were encountered by NWS, the major problem being lack of feedback of weather conditions at the site. This was resolved recently with the assistance of the Federal On-Scene Coordinator.

Table 2-4 was prepared by NWS to give some insight into the accuracy of the wind forecasts issued by NWS for the oil spill site. On-site winds were not relayed to NWS in Boston on a real-time basis until mid-January. Thus, operational forecasts were issued with the Nantucket Shoals Light Vessel (L/V) as closest observational site, located 32 miles from the spill site on Fishing Rip. Table 2-4A shows the wind verification based on Nantucket L/V data. Table 2-4B shows the wind verification for the Fishing Rip site. The tables are basically self-explanatory (MAE = mean average error). However, it should be pointed out that the selection of categories was subjective and based upon NWS operational experience, by which a forecast of wind direction that verifies within 30° is considered excellent. Forty percent of the forecasts (Table 2-4B) fell within this range; 72% of the forecasts fell within the range of 60°, considered a good-to-excellent forecast; and only 10% were in the 90° category, which is considered poor and of no ooperational use.

A wind speed in error by less than 5 knots is considered excellent (36% were in this category), less than 10 knots good to excellent (72% in this category), and greater than 15 knots unsatisfactory (12%). Even the last category can be of limited use depending on the strength of the wind.

While the table provides a statistical appraisal of the forecasts, it does not necessarily directly reflect their utility. That utility should be judged where possible on the overall effectiveness in assisting the OCS in making proper operational judgments.

One of the most serious problems arising from the spill was, and is, the potential contamination of the beaches and shorelines along the New England coast and possibly even the mid-Atlantic coast. Therefore, it was particularly important to accurately forecast offshore winds (260-360°) and onshore winds (90-160°). These were considered the two most important categories.

In evaluating the utility of the forecasts of the other wind directions, forecasts were definitely useful 84% of the time up to 12 hours and 81% of the time up to 30 hours.

Table 2-4. Verification of wind forecasts issued by NWSFO, Boston

A. Forecast vs. observed wind Nantucket Shoals L/V

	06 hrs	12 hrs	18 hrs	24 hrs	30 hrs	36 hrs	Summary
Number of cases	43	59	61	60	60	43	326
Wind direction MAE (^{o})	36.3	33.7	40.2	40.3	46.3	44.2	40.2
Wind speed MAE (kt)	6.0	7.3	7.0	7.0	7.6	7.2	7.0
% Distribution direction error							
Less than 30^o	49%	51%	49%	43%	38%	37%	45%
Less than 60^o	72	76	75	73	72	60	72
More than 90^o	09	05	13	08	13	09	10
% Distribution speed error							
Less than 05 kt	42%	31%	38%	32%	22%	40%	33%
Less than 10 kt	79	71	69	70	68	67	71
More than 15 kt	07	12	13	13	12	07	11
Average error vector (kt)	14.0	14.3	14.5	15.7	17.4	16.8	

B. Forecast vs. observed wind CG cutter on-scene Fishing Rip

	06 hrs	12 hrs	18 hrs	24 hrs	30 hrs	36 hrs	Summary
Number of cases	09	25	25	25	25	09	118
Wind direction MAE (^{o})	33.3	29.2	29.6	40.4	36.4	44.4	35.5
Wind speed MAE (kt)	6.3	5.8	7.4	7.5	5.9	6.1	6.3
% Distribution direction error							
Less than 30^o	44%	60%	44%	44%	56%	33%	49%
Less than 60^o	67	84	88	80	80	78	81
More than 90^o	00	04	04	16	12	11	08
% Distribution speed error							
Less than 05 kt	44%	44%	28%	28%	40%	44%	36%
Less than 10 kt	56	80	68	68	76	78	72
More than 15 kt	00	12	16	16	08	11	12
Average error vector (kt)	13.8	12.6	14.9	17.9	16.5	15.9	

2.2.7 Burning of Oil

The nation is faced with the problem of deciding whether to use burning agents in the event of a catastrophe such as the *Argo Merchant*. The usefulness of having an operational burning system can be envisioned in this situation. For example, had the *Argo Merchant* been given permission to dump some oil to extricate itself, the oil may have been rendered harmless if an operational burning system had been available. In lieu of this, two attempts were made to burn off the oil spilled from the tanker. The second of these consisted of a planned experiment to test the feasibility of using burning agents and to determine the extent to which such agents would consume oil in actual at-sea conditions. The material used was composed of extremely fine particles of fumed silica, surface treated with a silane coating to render it hydrophobic. Originally, the material was marketed under the trade name CAB-O-SIL ST-2-0. A detailed description of the burning theory is given by Tully (1969). This same material, identical in all respects, is now marketed under the trade name Tullanox 500, under a licensing agreement with the Cabot Corporation.

Numerous burning experiments and demonstrations were undertaken before 1971. Actual oil spills where burning was attempted include the *Torrey Canyon* spill in 1967; the *Arrow* in 1970 (Canada Ministry of Transport 1970a); and the *Othello* in 1970 (Fribeiger et al., 1971, 1970a). With regard to the *Arrow* spill in Chedabucto Bay, Nova Scotia, the following is an excerpt from the report by the Canada Ministry of Transport (1970a):

"From a review of the state-of-the-art and from the limited experiments on burning in Chedabucto Bay, it appears feasible to burn fresh Bunker C slicks if certain conditions are met..., but for it to be a practical operation, major advances must be made in the techniques of containment, ignition and maintenance of combustion (wicking agents)."

In 1970, the First Naval District conducted sea trials in which two burning agents were used: SEABED, a Pittsburgh Corning product, and CAB-O-SIL. Both products burned an estimated 10,000 of the 15,000 gallons Bunker C oil spilled. The amount each agent burned is not known, but CAB-O-SIL burned for about 16 minutes and SEABED for 4 minutes in swells of 8 to 10 feet and in seawater temperatures of 44°F. The COMDT First Naval District's report on this controlled oil spill (1970) contains the following findings.

(a) Bunker C oil spilled in its natural state on cold water will not support combustion without a wicking agent.

(b) The seeding methods demonstrated and the ignition methods attempted are both inadequate for normal at-sea conditions, wind wave and action being the determining factors.

(c) Subject to satisfactory ignition methods, both products tested will provide a wicking action and support combustion of cold Bunker C oil when adequate coverage is obtained.

As noted in most of the reference literature, of prime importance for successful burning is the dispersal of the powder in order to obtain a continuous coating over the oil slick. In the first attempt, on December 27, to burn the oil spilled from the *Argo Merchant*, USCG dropped isolated boxes of Tullanox 500 charged with JP-4 fuel from a helicopter and ignited them with a timed thermite grenade. The isolated boxes burned, but, because of the lack of dispersal of the wicking agent, flame spread was not substained (Photographs 42 and 43, Appendix III).

On December 29, the USCG Research and Development Center was requested to conduct a burning experiment on the *Argo Merchant* oil spill from the USCG *Spar*. After consultation with the On-Scene Coordinator the same day, a method of conducting the experiment was agreed upon.

Two days later, on December 31, the *Spar* arrived on the scene at daybreak, but was unable to sight a suitable oil slick without the aid of aircraft. The HU-16E (7524) was dispatched, reached the scene at approximately 1400, directed the *Spar* to a pancake by 1500, and the experiment began at 1500. The 90- by 120-foot slick was elliptical in shape, of heavy tarry consistency, and 6 to 10 feet thick (Photograph 44, Appendix III). It contained much debris, such as two-by-fours and other building materials. As the vessel maneuvered alongside, the patch broke into several smaller ones.

The Tullanox 500 dry powder was left in the original 11-pound plastic supply bags and thrown near the center of a small 30- by 60-food oil slick. Some bags burst open on impact. Others were torn open with birdshot from a 12-gage shotgun. Despite Tullanox 500's advertised affinity for oil, its bulk density of 3 pounds per cubic foot, comparable to cigarette ash, allowed the wind to blow approximately 95% of it (66 pounds) off the slick. Another 66 pounds were therefore charged with JP-4 and dispersed along the edge of the slick. It was obvious at this stage of the experiment that a continuous coating over the oil slick could not be obtained although sufficient wicking was dispersed to theoretically put a 12-inch coating over the 30- by 60-foot oil slick had 100% of it remained on the surface. In all, 55 gallons of JP-4 were used, in which three cotton sheets were soaked and distributed on the slick as primers. One sheet was ignited with 30-minute flares and burned for 4 minutes. The heat source was insufficient to ignite the primer, which was being mixed with water by the turbulence from the *Spar*. Attempts were made to ignite a wider area with flares (Photograph 49, Appendix III), but they were unsuccessful and the experiment was called off.

The following conclusions can be drawn from the second attempt to burn off the *Argo Merchant* oil:

(a) Dispersal of the wicking agent at sea to obtain a nearly uniform and continuous coating over an oil slick is not feasible with Tullanox 500 in its present form.

(b) A surface vessel operating close to the oil slick will cause it to break up.

(c) If a more uniform distribution of wicking agent and primer had been achieved, and the weathered oil had been susceptible to being burned, there is reason to believe the ignition technique used would have been adequate.

2.2.8 "Tar Ball" Reports

On March 10, large tar balls began coming ashore on the southwest coast of Nantucket Island. The balls were reportedly as much as a foot in diameter; one, found on the eastern shore of Nantucket, weighed 70 pounds. The material was deposited in a widely scattered pattern around centers about 100 feet apart. The tar was relatively fresh and contained no entrained sand or other materials, suggesting that it had been floating and weathering after a recent spill.

Samples of the tar were given to Dr. John Farrington at WHOI for chemical analysis. This work may be able to document the tar as being derived from crude or refined petroleum; but it will not be able to establish conclusively whether the tar originated with the *Argo Merchant* spill or with another No. 6 fuel oil spill.

2.3 Oil Trajectory Modeling Efforts

Several independent modeling efforts were made to explore the implications of the *Argo Merchant* oil spill, some of which were provided the Federal On-Scene Coordinator (OSC) for operational forecasting of the oil distribution. Cmdr. C. Morgan, an oceanographer, who was assigned to the OSC Staff from the USCG Oceanographic Unit, played a principal role in incorporating the efforts made available on scene into operation decision making. Other efforts whose results were not forwarded to the OCS are included for comparison and completeness. The six modeling efforts presented include "forecast" trajectories based on predicted or actual winds and currents, as well as "risk" trajectories which used climatological or historical winds and currents. Validation efforts by the contributor included comparison of forecast trajectories with observed oil location as well as confirmation of climatological wind pattern with observed winds.

All the models incorporated vector addition of the forces that moved the oil, which included winds, tides, and semipermanent currents. In general, differences in the model outputs are attributable to: (1) different sources of winds, whether measured, forecasted, or climatological; (2) different sources of currents, and (3) differences in how wind drift, both surface water and oil/water differential, was included. Table 2-5 summarizes the input data and the major techniques used for the six models or an aid for comparison.

All the models predicted that the oil on the surface would be moved offshore under the influence of the prevailing westerly winds. Since the actual winds were more towards the east than the climatologically predicted southeast, the forecast models appear more accurate in predicting the movement of the surface oil than the risk models. Additionally, those models which used tidal or net tidal currents rather than mean or climatological currents are

Table 2-5. Summary of model techniques and inputs

Model (text ref.)	Type	Classification	Source of winds	Source of currents	Wind effects
USCG Oceanographic Unit (sec. 2.3.1)	Forecast	Deterministic (updated by observation)	Observed on site and NWS forecasts	Tidal predictions (Haight, 1942)	Ekman wind drift (Jelesnianski, 1970) plus 1.2% of wind speed at 0° relative for oil movement
USCG R & D Center (sec. 2.3.2)	Forecast	Deterministic (worst case)	Observed on site and NWS forecasts	Tide table predictions	3.5% of wind speed at 0° relative
CEDDA (sec. 2.3.3)	Risk	Deterministic average	15-year historical record from Nantucket Light Ship	None and 0.25 kt at 270°	3% of wind speed at 15° to right of wind
USGS (sec. 2.3.4)	Risk/ hindcast	Statistical (probability matrix)	5-year historical records from towers on Georges Bank and Nantucket Shoals, and observed on site	Mean monthly (BLM, EIS, and Bumpus, 1973)	3.5% of wind speed at 0 or 20° to right of wind
URI (sec. 2.3.5)	Risk	Statistical (Monte Carlo)	10-year climatological wind rose from U.S. Naval Weather Service Command	Tidal (NOS chart)	3.5% of wind speed at 0° relative (1.5° surface drift plus 2% oil for oil)
URI (sec. 2.3.5)	Risk	Subsurface risk	None	Mean monthly (BLM, EIS, and Bumpus, 1973)	None

also more realistic, presumably because the mean currents generally include a surface drift resultant from the mean winds which was not separately removed before the wind-induced currents were added. The sole contribution for subsurface drift (Section 2.3.6) presents results which have not been verified to date.

The following six sections contain the contributed modeling efforts. It should be noted that the majority of the figures contributed are contained and referenced in Appendix VII.

2.3.1 U.S. Coast Guard Oceanographic Unit

The primary technique used by the USCG Oceanographic Unit in forecasting oil drift from the *Argo Merchant* was to sum the vector effects of wind currents, tidal currents, sea currents (mean or residual currents), and oil leeway. Based on 24-hour forecast winds for the spill site, provided by the National Weather Service in Boston, the forecast was made at about local noon each day for a verification time of 1300 the following day. The summation was done by a program from the following inputs:

- o Initial oil positions at 1300 the previous day.
- o Observed winds up to the present.
- o Forecast winds up to 1300 the following day.
- o Tidal currents.
- o Wind currents.

Program output was oil positions at 12-hour intervals from 1300 the previous day to 1300 the following day. A new blob of oil at the wreck site was generated every 12 hours. The positions obtained were reported by telephone each day about noon to Cmdr. Morgan, who would prepare forecast limits of all oil from these positions. Often a correction would be applied to the positions based on the difference between the forecast and the oil observed the preceding day. This correction represented the sea current, which was initially part of the computer program, but was later dropped.

The wind current used was a time-dependent Ekman model based on equation (41) in a paper by Jelesnianski (1970). The tidal current was derived from tidal vectors near the wreck site as given by Haight (1942). The oil leeway was taken as 1.2% of wind speed, directly downwind, based on measurements taken on the scene by the NOAA-USCG SOR Team.

For the first few days of the *Argo Merchant* oil spill, and after January 8, manual techniques were used for forecasting, which is continuing at the present time. Plans are underway to perform a more thorough analysis in the near future of the computer forecast technique based on observed winds.

With few exceptions, all oil sightings fell within the forecast oil limits. Examples of these forecasts are shown as box outlines in Figures VII-

22 to VII-29 (appendix VII). A major positive factor affecting performance in forecasting limits was the daily oil surveillance flights from December 17 to December 27. Data from these flights permitted accurate correction of initial oil position each day.

2.3.2 U.S. Coast Guard Research and Development Center

The USCG R&D Center began to forecast the movement of the oil on December 15, 1976, at the request of the Marine Safety Office (MSO) in Boston. The forces that transport the oil were examined by R&D Center personnel. It was found that the magnitude of the wind vector determined from predicted values of wind speed would move the oil at a rate of 0.5 to 1.5 knots in a downwind direction; that the magnitude of the tidal currents would move the oil at 0.5 to 1.3 knots; and that the magnitude of the permanent currents in the area are approximately 0.1 to 0.2 knots. After comparing the magnitude of the forces that move the oil it was decided that for the short-term predictions (24 hours) the tides and winds would control the movement of the oil. For long-term predictions, the winds alone would dominate. The method used for predicting the movement of the oil was a simple vector addition of the tidal vector and 3.5 percent of the wind speed on an hourly basis. The lateral movement of the oil was determined to be the magnitude of the tidal movement. This combined with the hourly vectoral movement of the oil showed the "worst case" estimate of the areal extent of the oil.

On December 16, at 0930, MSO, Boston, requested the R&D Center to forecast the movement of oil should the tanker rupture. At 1135, MSO was informed that the oil would move southeast for the next 24 to 48 hours, and would continue to move southeast-to-east through the weekend of December 18 and 19. This forecast was based on the tides and the predicted winds supplied to the R&D Center by the National Weather Service (NWS). MSO, Boston, was also informed that the oil would continue to move offshore as long as the winds were offshore.

Figures VII-9 through VII-12 in Appendix VII depict the long-term predicted movement of the oil using predicted winds and net tidal currents. These figures were the basis for the information that was transmitted to MSO, Boston. The long-term movement is based on the predicted winds as supplied by NWS. Figure VII-9 shows the predicted limit of the slick as of 1900, December 17. This figure includes the effects of the predicted winds used for the forecast as well as the total movement of the oil caused by previously predicted winds. From 1600, December 16, the west-northwest winds and tides moved the oil 8 miles to the east-northeast. From 0700 to 1300, December 16, the northeast winds moved the oil toward the southwest, a distance of 6 miles. The spill was treated as a continuous leak, and the oil movement was therefore predicted continuously from the site of the *Argo Merchant*. This is the reason for two vectors being labeled 0700-1300, December 16. One of these shows the transport of the oil that moved northeast prior to these wind conditions. The other vector shows the movement of oil from the site of the *Argo Merchant* during the period 0700-1300, December 16. This process was used for the entire period. Thus, the boundaries of the oil spill limits as shown in Figures VII-9 through VII-12 are, in essence, an estimate of the limit of the oil slick.

Figure 2-8 is a comparison of the limit of the slick on December 21 as observed on overflights and the "worst case" estimate of the limit predicted from the winds as of 2400, December 20 (figure VII-11) In figure VII-13, the observed limit of the slick on December 23 is compared with an estimate of the limit as of 0700, December 23 (figure VII-12). Again, the observed limit of the slick was obtained from overflights of the area. In these two figures, the predicted direction of movement of the oil is in agreement with the observed movement, and the predicted areal coverage is about twice the observed. The entire prediction was accomplished in approximately 3 hours after the time of request from MSO, Boston. It indicates that vectoral addition of the forces that move the oil is an excellent method for a quick answer to where the oil will go and when it will get there. Had the winds been onshore instead of of offshore, this method would have enabled cleanup equipment to be placed at strategic areas before the oil came ashore. In addition, it seems likely that had actual on-scene winds been used in the forecast rather than long-term predictions from NWS, the predicted movement and dispersion would have been even more precise.

Figure VII-14 is a progressive hourly wind vector diagram derived from 3.5% of the on-scene wind speed data for the period 1600, December 15, to 0700, December 23, collected by the USCGC *Vigilant*. These wind data together with tidal data can be used to compare actual short-term movement of the oil with the predictive technique of adding winds and tides vectorially. In addition, the validity of using 3.5% of the wind speed data in a downwind direction can be examined.

For short-term drift, Figure 2-9 gives a comparison of observed slick and predicted movement caused by tides and winds. The vector shows the predicted movement of the oil for the period 2400, December 15, 1976, to 0900, December 17, 1976. The outline of the slick was taken from slick map IV-1 in Appendix IV, which shows its location near noon on December 17. There is excellent agreement between the actual direction of the oil movement and the predicted movement as determined from tides and wind. In fact, it appears that 3.5% of the wind speed data adequately describes this transport vector. The greatest error occurs in predicting the tidal component for each hour of movement.

From December 15 to December 19, the total extent of the spill was not clearly defined by overflights. However, several observations of the movement of the oil during and after this period verify the techniques used by the R&D Center. These observations are shown in Table 2-6. The observed movement of the oil spill is documented in the maps contained in Appendix IV. Table 2-6 indicates that the oil was moving westward, bearing 240°T, on December 16. On December 18, pancakes were found 27 miles east of the ship (090°T). The maximum eastward movement of the oil caused by the wind (Figure VII-14) was 31 miles, bearing 130°T. Assuming this is the maximum eastward extent of the oil, the computed wind factor for moving it would be 3.05%. Beginning with December 20, the daily wind factor for the observed movement and the direction of movement of the oil are given in Table 2-6. A summary of these values compared with predicted values is shown in Table 2-7.

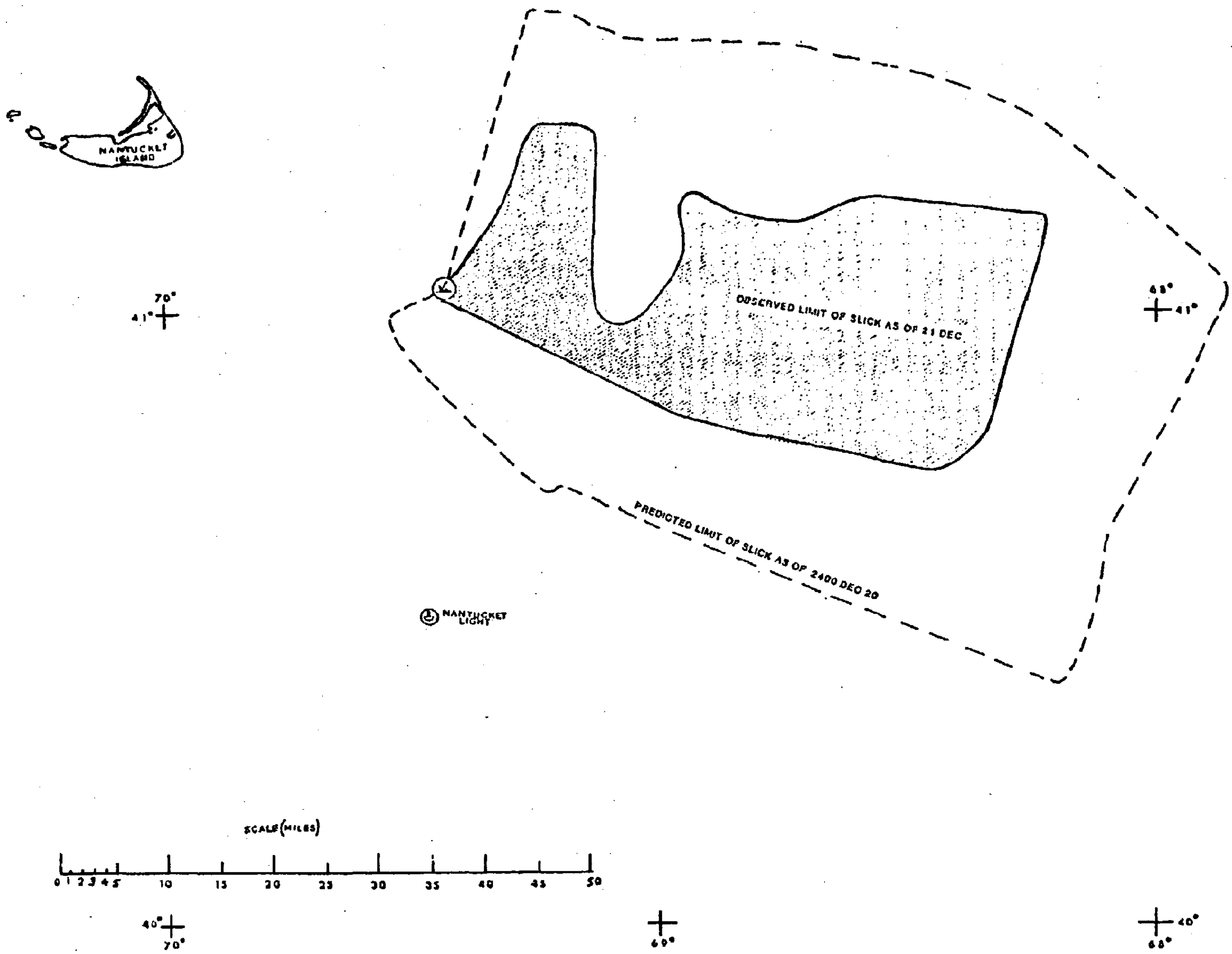


Figure 2-8. Comparison of observed and predicted limit of slick, December 21.

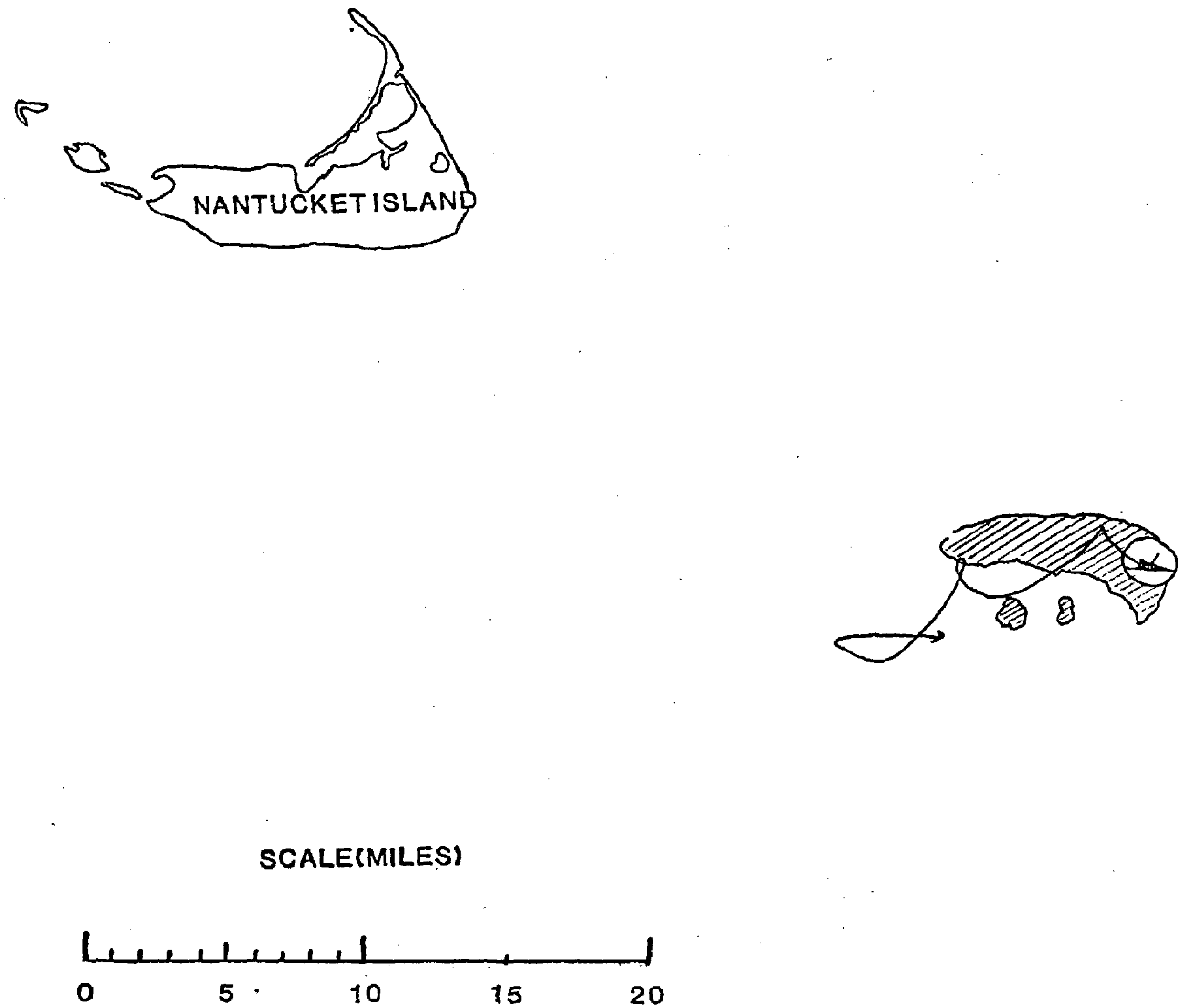


Figure 2-9. Comparison of observed slick (cross hatch) and predicted movement (line) by tides and winds for December 17, 1976.

Table 2-6. Observations of oil movement

Date (1976)	Actual observations	Predicted movement of oil based on 3.5% of wind data in downward direction
12/16	Oil 2 miles north to south and 4 miles east to west; oil moving west; streak of oil, bearing about 240°T.	Winds during the morning of December 16 would move oil on a bearing of 245°T.
12/18	Pancakes 27 miles east of ship (090°T). Computed wind drift 3.05%.	Maximum movement east 31 miles, bearing 130°T.
12/20	Main plume 16 miles long, bearing 040°T. Computed wind factor 4.00%.	Winds from 0900, December 19, to 0900, December 20, would move oil 14 miles, direction 048°T.
12/21	Maximum eastward movement of oil 53 miles, direction 090°T. Computed wind factor 3.09%.	Maximum eastward movement 60 miles, direction 095°T.
12/22	Maximum eastward movement of oil 95 miles, direction 108°T. Computed wind factor 4.05%	Maximum eastward movement 82 miles, direction 106°T.
12/23	Maximum eastward movement of oil 86 miles, direction 100°T. Computed wind factor 3.10%.	Maximum eastward movement 97 miles direction 110°T.

Table 2-7. Observed vs. predicted movement

Date	Observed		Predicted	
	Wind Factor	Direction	Wind Factor	Direction
12/20	4.00%	040°T	3.5%	048°T
12/21	3.09%	090°T	3.5%	095°T
12/22	4.05%	108°T	3.5%	106°T
12/23	3.10%	100°T	3.5%	110°T

One-way analyses of variance (anova) without replication were performed to determine whether statistically significant differences were detectable between observed and predicted wind factor and direction. The results are summarized in Tables 2-8 to 2-11.

The following conclusions can be drawn from the above analysis:

- For short-term predictions (24 hours) a vectorial addition of wind and tides adequately forecasted movement.
- For long-term predictions the winds dominated the movement of the oil.
- 3.5% of the wind speed is an adequate value for the wind drift factor.
- Oil spills tend to move downwind.

2.3.2 Center for Experiment Design and Data Analysis

Another modeling study was carried out by NOAA personnel at the Center for Experiment Design and Data Analysis (CEDDA) at the request of the OSC on December 28. In this study, a wind drift (3% at 15° to the right), based on 15 years of historical wind records from the Nantucket Light Ship were considered both alone and in combination with an assumed local current estimated from measurements taken at WHOI's location site D (0.25 knots at 270°). Several cases were run using both winter (January-February-March) and spring (April-May-June) wind records. These modeling results were forwarded to Cmdr. Morgan for his use in upgrading the forecasting effort.

At CEDDA, the centroid of hypothetical spills were tracked to model the probability of impact from an offshore oil spill. Such processes as oil spreading and weathering were not included. Tidal currents were neglected, and surface slick movement was considered to be a linear combination of a seasonal baroclinic current (sea current) and a time-dependent wind-driven current. The spatial field of seasonal baroclinic currents was input to the computer program, and a wind-driven current vector was calculated based on a 3% wind factor adjusted to include a 15° Coriolis deflection angle between wind drift and wind vectors. The wind field was taken directly from coastal meteorological station data at Nantucket Light Ship from 1955 to 1970, obtained from the National Climatic Center in Asheville, North Carolina.

A hypothetical path of oil movement was generated by computing trajectories from each third hourly wind observation. After each 3-hourly step, the geographical position of the centroid of the hypothetical slick was compared with the beach location. When this position and the beach location coincided, an impact event was assumed and the procedures terminated. Upon impact, the wind record used for the wind-drift current calculation was advanced 72 hours and modeling of a new spill event was begun. If no beach impact was found within a modeling time of 1200 hours, the oil mass was assumed degraded and the procedure again terminated. Approximately 40

Table 2-8. Data array for wind factor

Date	Observed	Predicted	
12/20	4.00	3.5	
12/21	3.09	3.5	
12/22	4.05	3.5	
12/23	3.10	3.5	
	$\bar{x}$ 3.56	$\bar{x}$ 3.5	$\bar{\bar{x}}$ 3.53

Table 2-9. Anova for wind factor

Source of variation	Amount of variation	Degrees of freedom	Estimated variance	Observed F ratio
Among	0.0072	1	0.0072	
Within	0.8662	6	0.1444	0.0499
Total	0.8734	7		

Conclusion: For the 5% level of alpha there is no significant difference between the observed and the predicted wind factor.

Table 2-10. Data array for predicted movement (°true)

Date	Observed	Predicted	
12/20	040	048	
12/21	090	095	
12/22	108	106	
12/23	100	110	
	$\bar{x}$ 84.50	$\bar{x}$ 89.75	$\bar{\bar{x}}$ 87.13

Table 2-11. Anova for wind direction

Source of variation	Amount of variation	Degrees of freedom	Estimated variance	Observed F ratio
Among	55.13	1	55.13	0.06
Within	5247.75	6	874.63	
Total	5302.89	7		

Conclusion: For the 5% level of alpha there is no significant difference between the observed and the predicted wind directions.

minutes of computer processing unit time was required to run the oil advection model with 10 years of historical wind data.

The results of simulated spills at the site are presented as probability diagrams. Figure 2-10 shows the results for no currents and winter winds, while Figure VII-15 (appendix VII) is the same except for spring winds. Figures VII-16 and VII-17 show winter and spring winds, respectively, combined with a sea current of 0.25 knots in a westerly direction. About 450 spills were simulated for the spill site. These diagrams indicate the impact, in percent, that a 10-mile by 10-mile offshore area would receive by the calculated oil trajectories on a seasonal basis. As indicated by these diagrams, oil movements from the spill site shows a strong offshore tendency.

2.3.4 U. S. Geological Survey, Systems Analysis Group

A fourth numerical modeling study was done by T. Wyant, D. A. Smith, and J. Slack of the USGS Systems Analysis Group in Reston, Virginia. The results of this study were not part of the on-scene effort, but they do provide an opportunity to verify, apply, and extend an oilspill trajectory model previously developed as part of an oil spill risk analysis for the proposed North Atlantic Outer Continental Shelf lease area. The latter analysis was done to determine environmental hazards of developing offshore oil in the region and has been described in detail by Smith et al. (1976). In the risk analysis, model runs were used to estimate probabilities that spills occurring at anticipated production sites would have an impact on certain biological and recreational resources in the North Atlantic coastal region. When the *Argo Merchant* broke up in this area, it became possible to compare model output with observed movements of the spill. Also, since model input for the area was fully prepared before the incident, it was possible to make short- and long-term forecasts of slick behavior from the moment the tanker went aground.

The USGS oil spill trajectory model was constructed and used to simulate oil slick movement on a digital map of the North Atlantic between 38°N and 45°N latitude and 65°W longitude and the North American coast. The fundamental transport equation in the model expresses oil slick movement as the vector sum of residual surface current velocity, tidally averaged, and 3.5% of wind velocity. Slick movement was simulated as a series of straight-line displacements, each representing the joint influence of wind and current over a 3-hour period. Monthly surface current velocity fields were provided by the Bureau of Land Management and were based in part on drift bottle studies conducted by Bumpus (1973).

Wind velocities were provided for the simulations in one of two ways, depending on the mode of operation of the model. First, for purposes of verification, wind observations were input directly and updated every 3 hours. Wind reports were received for two locations: Nantucket Light Ship, and the USCGC *Vigilant*, which was on the scene of the grounding. Second, for purposes of forecasting, prevailing wind velocity was used for the first 3-hour step, and all subsequent 3-hourly winds were randomly generated from a

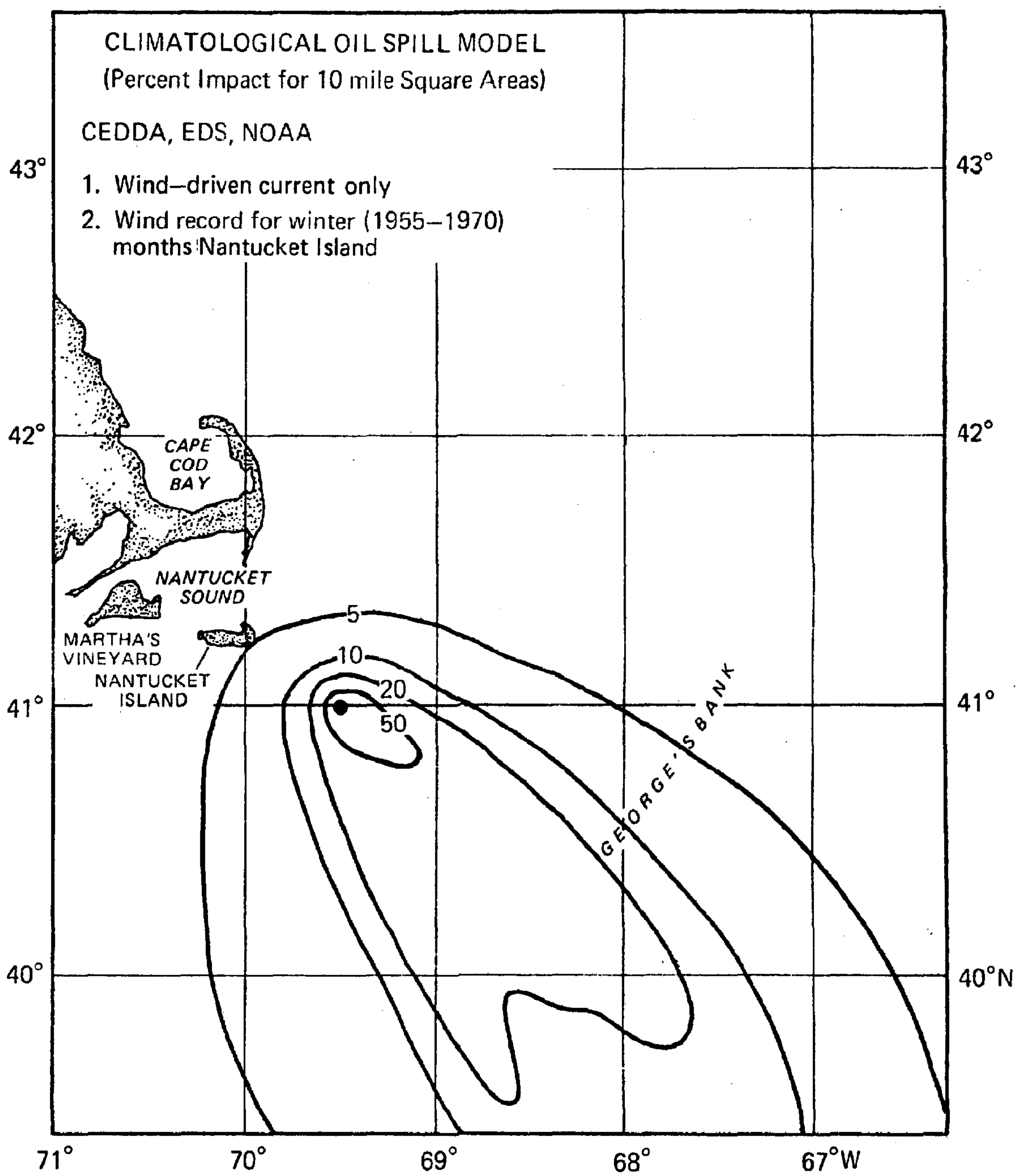


Figure 2-10. Impact probability for winter (no current).

wind transition probability matrix. Seasonally specific first-order transition matrices were derived from historic data covering 5 years of observations at the Georges Bank and Nantucket Shoals weather towers.

Surface current velocity fields used in the model were the same for both verification and forecasting modes, but changed from December to January. Two wind drift angles, 0° and 20°, were used in the trajectory simulations, and sensitivity of the results to this parameter is discussed below.

Before the grounding of the *Argo Merchant*, model runs conducted as part of the oil spill risk analysis for the Georges Bank area had indicated that by far the most likely trajectory for oil spilled in that area would be to the southeast (Figure 2-11), a result which was later borne out in movements of *Argo Merchant* slick. However, the opportunity for more detailed and precise testing of the model arose with the availability of voluminous data on slick location and winds provided by NOAA and USCG personnel on the scene and by National Weather Service offices in New Jersey and Boston.

Time series of observed winds were input to the model in order to make deterministic simulations of slick trajectory. A series of points were released every 3 hours from the site of the *Argo Merchant* grounding and transported as described above by currents and observed 3-hourly winds, beginning with the reported wind at 1600, December 17. A display of all such points after n time steps should resemble the location and general shape of the slick at a time 3n hours from 1600, December 17. Figures 2-12 and Figures VI-18 to VII-21 show displays for two dates in December, based on observed winds from two locations. Maps of the actual slick were provided by NOAA and USCG personnel involved in overflights of the area. The model predictions do not take into account differential rate of oil released from the ship or oil dispersion over time. In Figures VII-17 to VII-19 the wind input is not modified by any assumed drift angle, and it is clear in Figure VII-19 that, in the case of wind data from the USCGC *Vigilant*, use of a drift angle to the right would have narrowed the gap between observed and predicted patterns.

One might be inclined to deduce from the above that wind data from the *Vigilant* were most representative of conditions along the oil slick and that choice of a positive drift angle was appropriate. However, although the *Vigilant* was at the scene of the *Argo Merchant* during this time, the Nantucket Light Ship was anchored near 40°30'N latitude, 69°29'W longitude, actually closer to the southeastern extremity of the slick. Thus, data from neither station were clearly preferable on the basis of location.

Figures VII-20 and VII-21 show comparisons of predicted and observed slick locations based on the assumption of a 20° drift angle to the right. In summary, no clear conclusions can be drawn concerning the best choice of wind station and drift angle in the absence of more information.

In the days following the grounding of the *Argo Merchant*, model runs were regularly made to estimate the probability that oil would ultimately affect the coast. In each run, large numbers of simulated trajectories were

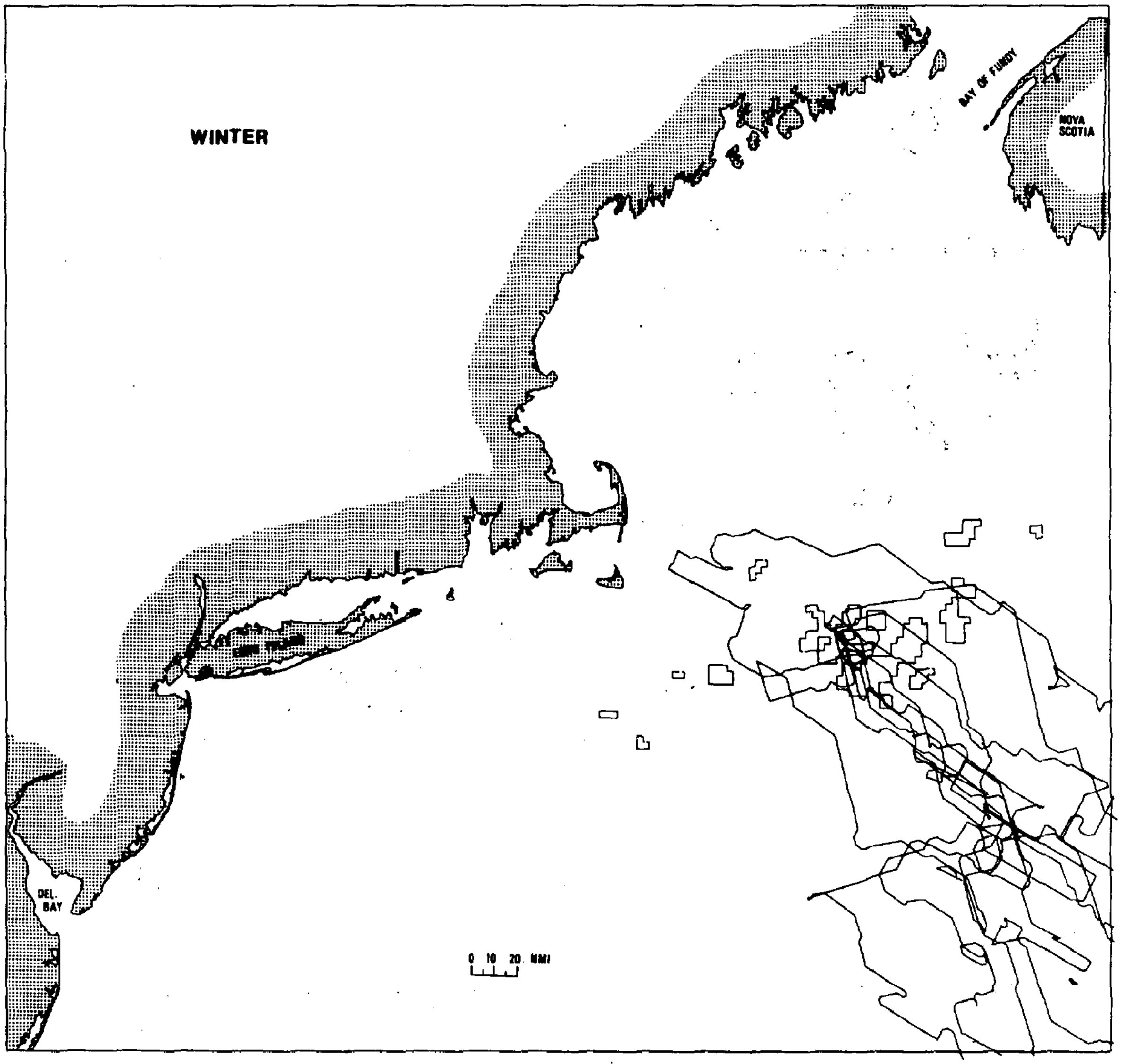


Figure 2-11. Example of oil spill trajectory results for the Georges Bank proposed lease area under winter conditions. (From Smith et al., 1976.)

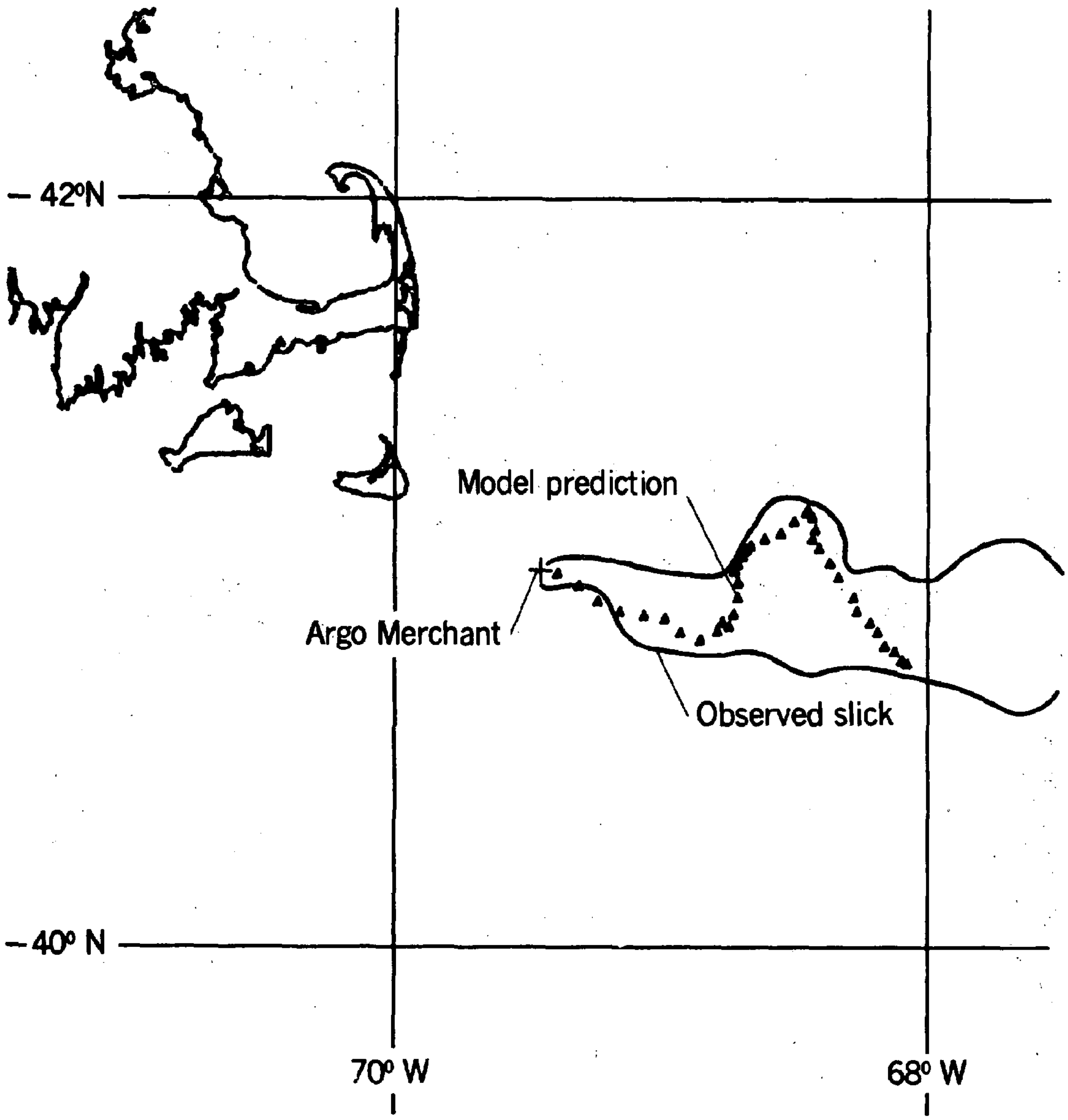


Figure 2-12. Predicted and observed location and shape of oil slick, December 22. Model prediction shows oil released from the *Argo Merchant* from 1000, December 17, through 1000, December 22. Wind input is from Nantucket Light Ship.

launched from the ship site, with initial wind velocities based either on National Weather Service reports or on random selection from historic wind data. Wind velocities for subsequent steps were generated from a wind transition probability matrix, as described earlier. Table 2-12 shows probability estimates for 2 different days in the period following the grounding. The sensitivity of probability estimates to initial wind conditions is evident.

Significant quantities of oil may still be contained in the hull of the *Argo Merchant*, and how the probability of this oil coming ashore will change in the months to come remains a question. Model runs were therefore conducted using different starting dates and initial wind velocities randomly selected from historic seasonal wind data. Table 2-13 demonstrates the sensitivity of probability estimates to seasonal conditions.

In January, the spill left the area for which model input had been prepared for the risk analysis. On the basis of data in the U.S. Navy Marine Climatic Atlas for the North Atlantic (Meserve, 1974), model inputs were prepared to continue forecasting oil trajectories in the Gulf Stream, although various modifications to the model were required.

The length of time steps used in the model was increased to 1 day. Winds at each step were randomly drawn from local historic frequency tables, rather than from transition matrices. Frequency charts of winds by month and location were obtained from the climatic atlas, as were prevailing currents at each step by season and location. Either a null current or the prevailing current was chosen at random at each step according to the reported "persistence" of the prevailing current.

Trajectories are located in a latitude-longitude coordinate system with displacements adjusted for earth sphericity. Model output takes the form of displays of simulated trajectories on maps of the North Atlantic.

Updated starting sites for model runs are determined by reported locations of a satellite-monitored NOAA drifting buoy deployed in the slick on December 31. As yet, no account has been taken of long-term weathering effects on the oil or the differential transport of the oil and the buoy.

Figure 2-13 shows the locations at 30-day intervals of 100 simulated trajectories launched from the reported position of the drift buoy on January 30. In this area of the Atlantic, the Gulf Stream divides into northern, eastern, and southern flows. This accounts for the wide spread in trajectories. In the future, when trajectories are launched from one division of the Gulf Stream, model runs should show much tighter clustering. Figure 2-13, indicates the northern flow to be the most likely of the three.

2.3.5 University of Rhode Island, Department of Ocean Engineering

Surface Currents

C. Noll, P. Cornillon, and M. Spaulding of the Ocean Engineering Department at the University of Rhode Island developed a simple computer model to predict the surface drift of spilled oil shortly after the *Argo Merchant* went

Table 2-12. Simulated trajectories from the *Argo Merchant* on different initial wind patterns (300 trajectories launched for each wind pattern)

Initial wind pattern	Probability ashore	Mean days to land
Initial wind selected randomly from historic winter record	0.10	8
Initial wind northeast 10 knots (reported by USCG, December 16)	0.24	5
Initial wind northwest at 20 knots (reported from Nantucket Light Ship, December 17)	0.07	8

Table 2-13. Simulated trajectories from the *Argo Merchant* based on different starting dates (300 trajectories launched for each month)

Date	Probability ashore in U.S.	Probability ashore in Canada (Nova Scotia)	Total probability ashore
December	0.10	0.00	0.10
January	0.08	0.00	0.08
February	0.14	0.02	0.16
March	0.33	0.09	0.41
April	0.40	0.12	0.52
May	0.33	0.34	0.67
June	0.34	0.58	0.92
July	0.34	0.57	0.91
August	0.28	0.31	0.59

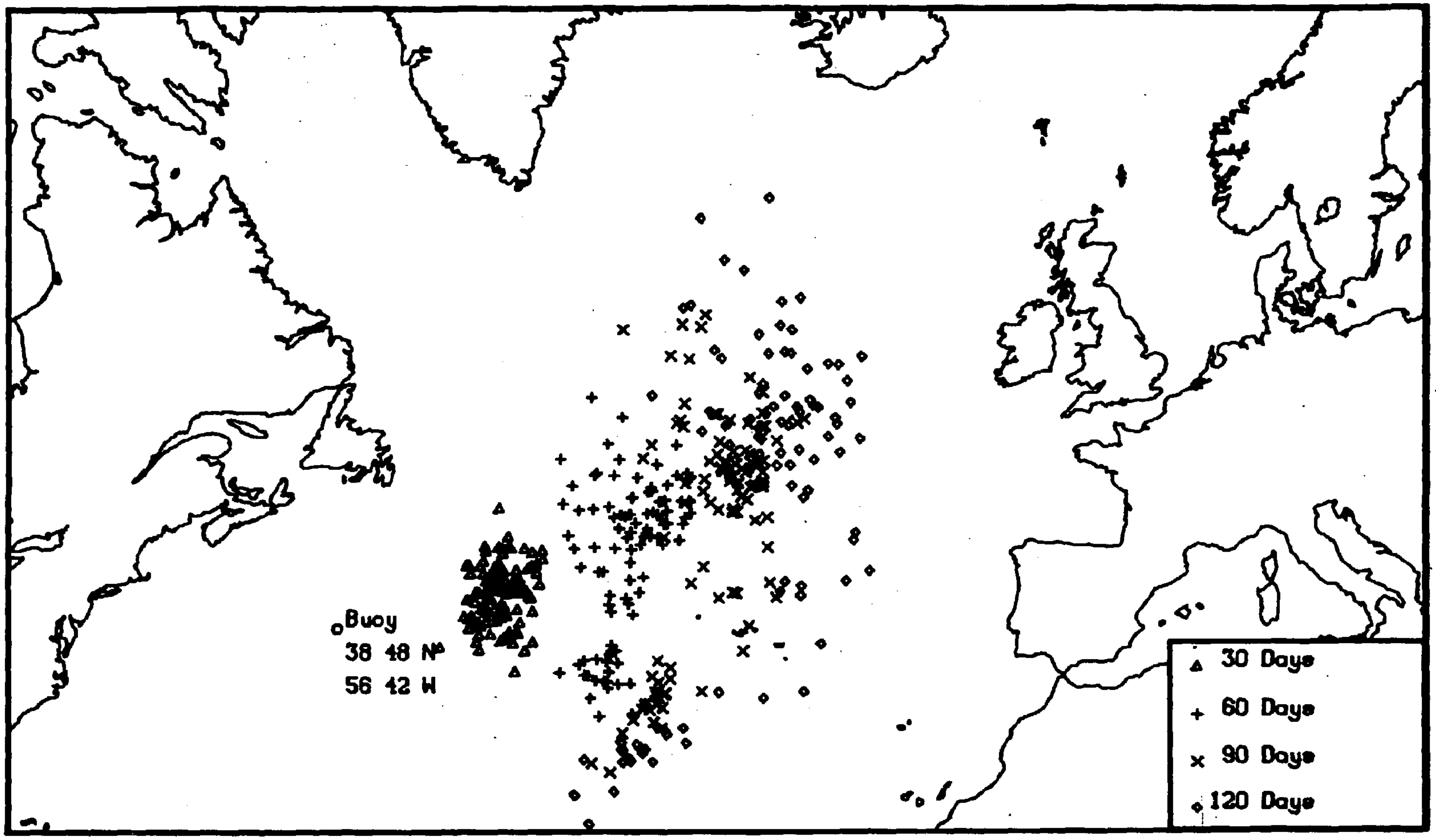


Figure 2-13. Locations at 30-day intervals of 100 simulated trajectories started from position of NOAA drifting buoy on January 30.

aground. This effort was supported by ERDA contract DY-76-S-02-4047. The model was written to allow for either a Monte Carlo prediction of the likely spill location as a function of time, sampling randomly from the 10-year average monthly wind rose for that area, or a deterministic hindcast of the spill location using actual wind measurement for the period of interest. Monte Carlo predictions of the location of the leading edge of the spill 5, 10, 15, 20, 25 and 30 days following the breakup of the *Argo Merchant* were generated for URI planning purposes shortly after the ship broke up. These predictions, as well as a 30-day deterministic hindcast, are presented here. In all figures, the forecast limits of oil by the USCG Oceanographic Unit (Section 2.3.1) are included for comparison.

Model Runs

Two cases of the deterministic model were run. The first (Figure VII-22, Appendix VII) included wind-driven currents only. It was assumed that the wind induced a surface drift in the direction of the wind at 3.5% of the wind velocity. This drift is accounted for by about 1.5% for the wind-induced water motion and about 2.0% for the relative oil-to-water motion (Smith, 1974). No Coriolis forces were included. The second case (Figure VII-23) included wind-driven currents and tidal currents which were added vectorially to yield the spill's overall movement. In both cases, starting date was December 18, and 30-day trajectories were calculated.

The model was run using 3-hour time steps, i.e., the spill was moved at the determined rate and in the determined direction for a period of time corresponding to 3 hours before the wind was changed. The necessary wind data were obtained from the Grant Point Coast Guard Station on Nantucket Island. The tidal currents were taken from the National Oceanic and Atmospheric Administration navigation chart 13006 (4/76).

As in the deterministic case, the Monte Carlo runs were made both for wind-driven currents and for wind-driven currents added vectorially to the local tidal currents. The wind speed and direction for the Monte Carlo runs were randomly sampled so that the probability of obtaining a given wind magnitude and direction equals the probability that such conditions are observed in the appropriate month during the past 10 years. These 10-year averaged data (U.S. Naval Weather Service Command, 1970) list the probability by month of obtaining the wind velocity in each of six ranges for each of eight wind directions (N, NE, E, etc.). Once a direction and magnitude had been chosen for the wind, the wind-induced drift of the oil was calculated and added to the tidal current. The slick was then moved at this drift rate for 2 hours, at which time the procedure was repeated. Figures VII-24 and VII-25 depict five representative spill trajectories for the wind-only and the wind-plus-tidal-current case, respectively. Figures VII-26 to VII-28 and Figure 2-14 represent the 5-, 10-, 20-, and 30-day Monte Carlo predictions corresponding to 200 trajectories in which the tidal current was included. Figure VII-29 represents, for comparison, the 30-day Monte Carlo prediction for which the tidal current was not included.

In all the plots shown in the above figures and figure 2-13, the projected path represents that of the leading edge of the oil slick. Thus,

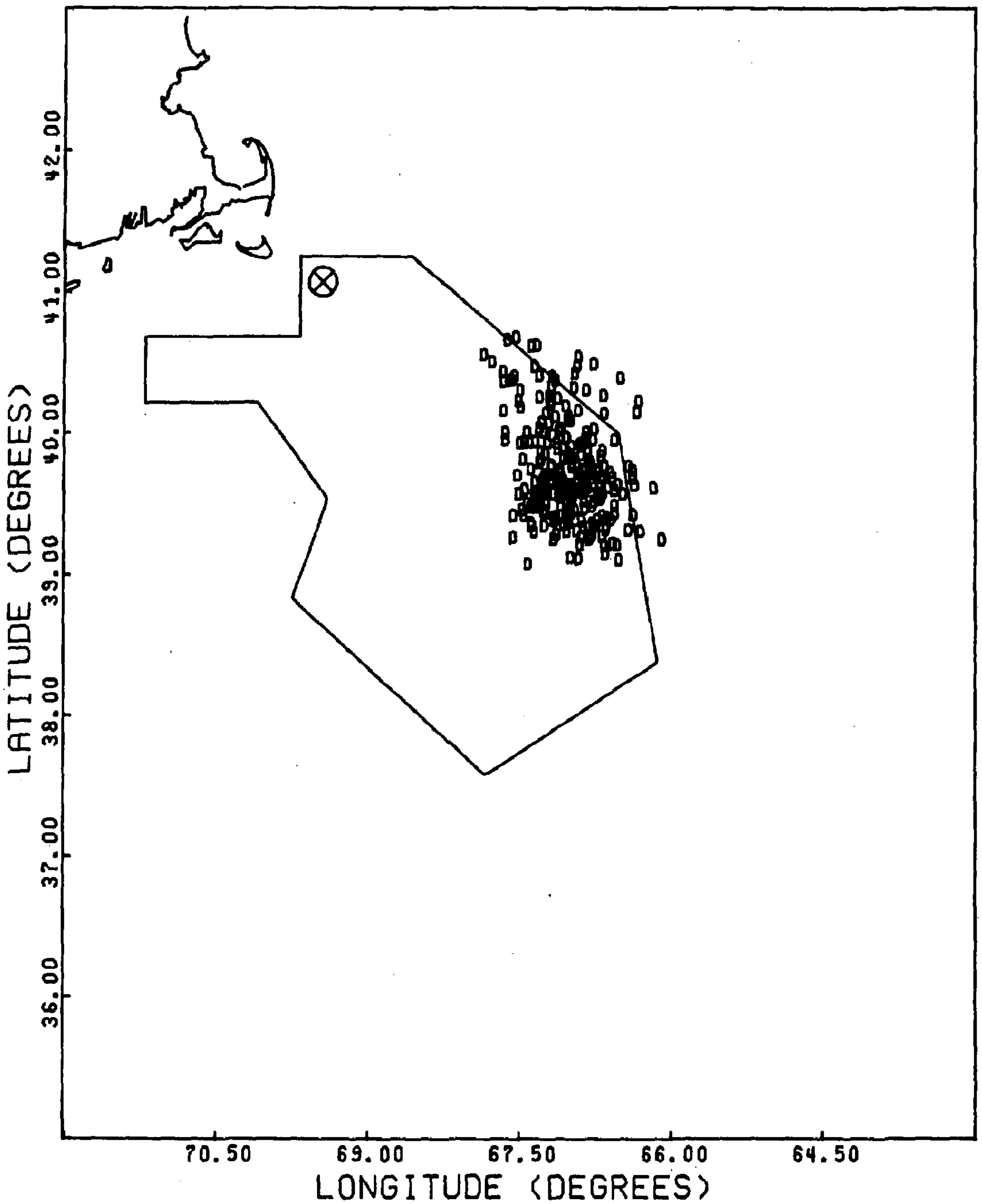


Figure 2-14. Twenty-day Monte Carlo prediction (wind and tidal currents).

theoretically, it represents the path of the slick after 30 days. The "x" surrounded by the circle represents the location of the *Argo Merchant*. The boxed-in area represents the limits of the slick after 30 days or as otherwise specified. The limits of the slick were provided by R. Griggs of the U.S. Coast Guard. Each "x" along the path represents the end of a 5-day period.

There are two different sets of Monte Carlo plots. One set (Figures VII-24 and VII-55) depicts five separate Monte Carlo trajectories. Each position of the leading edge of the spill is plotted every 2 hours for 30 days. The second, Figures VII-26 through VII-29 and figure 2-14, depicts a point for each 200 trajectories after 5, 10, 20, and 30 days. The area with the highest concentration of points indicates the most probable position of the leading edge. The limits of the observed slick have been added to each plot to aid in evaluating the accuracy of the predictions.

Discussion

The U.S. Naval Weather Service wind data for the Quonset region indicates that westerly and northwesterly winds predominate. This yields a general eastsoutheast movement of the oil slick. The trajectories calculated follow the direction of the actual slick until the 25 to 30 day period. At that time, the trajectories continue on their east-southeast path while the slick assumes an almost due east heading. This occurs near 68°N longitude and 38°W latitude. According to Sverdrup, Johnson, and Fleming (1942), the Gulf Stream in the New England Atlantic area is located between 68° and 60°N longitude and 37° and 41°W latitude and flows in an east-northeast direction at a speed of approximately 1 knot. Due to yearly changes and meanders, it is difficult to locate the Gulf Stream at any one time. Since only tidal currents are used in the models, this would explain the inaccuracy of the trajectories after 20 to 25 days. The addition of a strong east-northeast current when the slick reached the Gulf Stream would give more accurate long-term results.

Subsurface Currents

R. Gordon, M. Spaulding, P. Cornillon, and R. Halm of the Department of Ocean Engineering at the University of Rhode Island generated a model which predicted the subsurface drift of *Argo Merchant* oil. Directions of the monthly mean bottom velocity vectors for December and January in the spill area (Bumpus, 1973) as reported by the Bureau of Land Management (1976) in thesis draft Environmental Impact Statement for the North Atlantic Region were used along with estimates for maximum speed in the area (taken as 3.0 nautical miles per day throughout) as model input. A particle injected at the spill location (41°0'N, 69°30'W) was advected using the closet bottom velocity vector. A time step of 1 day was used.

Figure 2-15 shows the trajectory of a particle injected in the vicinity of the spill location (41.0°N latitude, 69.5°W longitude) near the bottom. The spill location is identified by a square (□) and subsequent positions at daily intervals are denoted by crosses (X). The bottom movement at first proceeds towards the southwest and after approximately 5 days heads west.

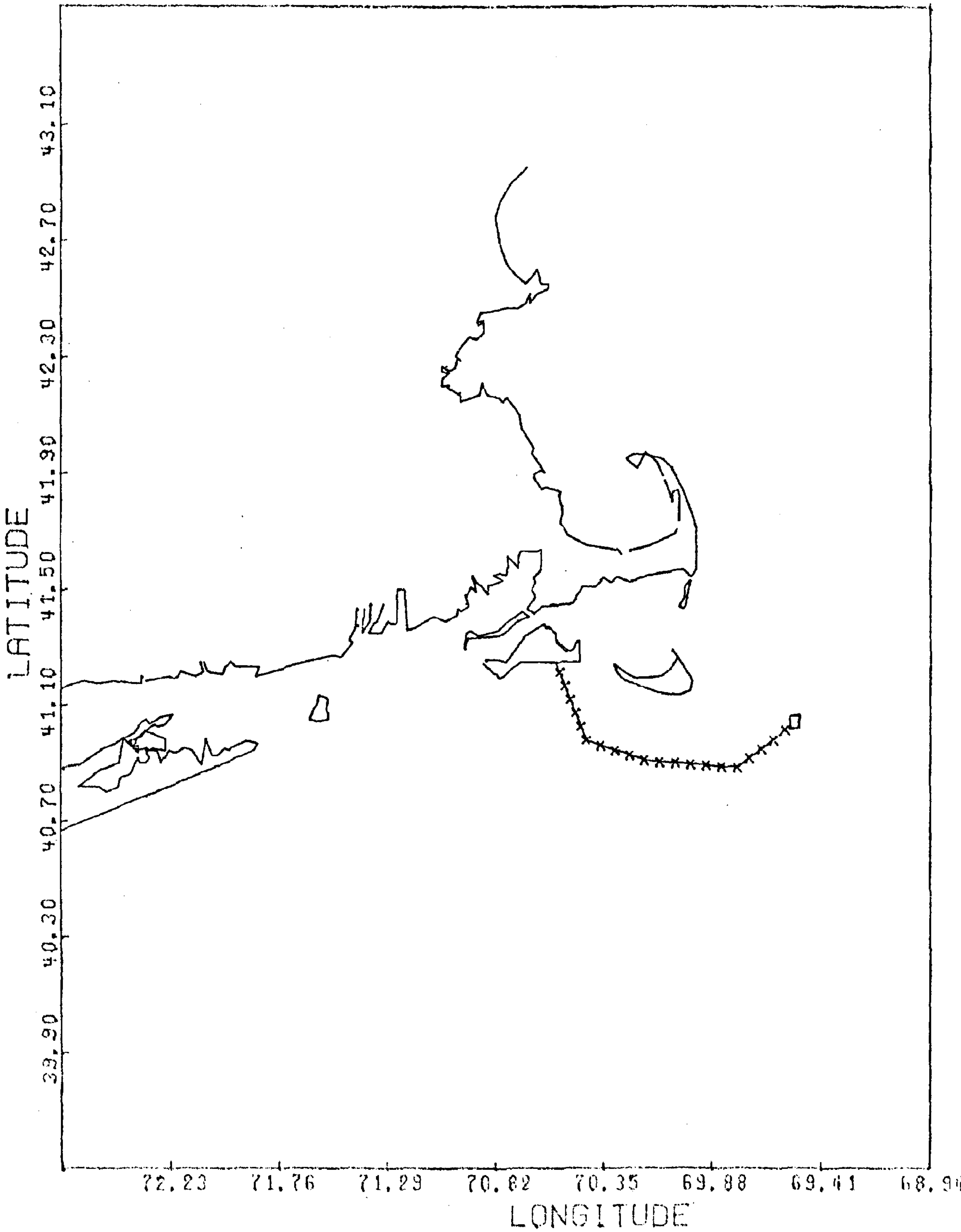


Figure 2-15. Bottom drift from the *Argo Merchant* wreck site based on subsurface drift data.

About 11 days after the injection, the bottom particle moves northwest and continues until it hits the shore at Martha's Vineyard 20 days after injection. It should be noted that of the directional data reported by Bumpus (1973), four data points were used (all at a speed of 3.0 nautical miles per day) to advect the particle.

2.3.6 Summary of Initial Modeling Results

Five different models were used to predict or hindcast the movement of the oil on the water surface, and, in general, they all were successful in establishing the general direction of drift. Conceptually, they all considered the oil as Lagrangian particles which were advected along by the currents and given a differential oil/water velocity related to the wind. Difference arose in what the models used for the advecting current fields and wind factors, and in the sources of the wind data (real-time winds, climatological wind series, or stochastic models).

In all cases the parameterizations were simple. The advective current fields used were externally specified and were either a general mean current, a predicted tide, or a correction term based on estimates of the errors in the last model up-date. Nontidal time dependence or topographically controlled regional currents were not modeled. The wind drift factor was intended to represent the net effect of Ekman currents, Stokes drift, and momentum transfer by waves. Options ranged from considering the Ekman drift explicitly, parametrically, or not at all. In all models some form of down-wind motion was used, with the magnitude depending upon whether the Ekman drift was considered separately or not.

In general, the models reflect a wind-dominated transport for the oil, and the real-time winds coincide fairly well in direction with the climatologically derived winds. This makes the model all behave in a similar manner, and it is difficult to evaluate the relative accuracy of the slightly different approaches. For the *Argo Merchant* the models all gave useful and encouraging results. A more critical test will come in an advectively dominated region with complex coastal morphology.

References

Bumpus, Dean F., 1973. A description of the circulation on the continental shelf of the east coast of the United States. Progress in Oceanography Vol. 6, pp. 111-157.

Bureau of Land Management, 1976. Draft Environmental Statement for the Outer Continental Shelf off the North-Atlantic States, U.S. Department of Interior, Visual #2.

Report of the Task Force - Operation Oil (Clean-up of the Arrow oil spill in Chedabucto Bay, July 1970a, Canada Ministry of Transport.

COMDT First Naval District letter to CNO file 3120 ser 153 of 4 Jun 1970b.

Colton, J. B., and R. R. Stoddard. 1972. Average Monthly Sea-Water Temperatures Nova Scotia to Long Island, 1940-1959. Serial Atlas of the Marine Environment, Folio 21 Amer. Geogr. Soc., New York.

Fribeiger, Arnold, and John M. Byers. Burning Agents for Oil Spill Clean-up,: 1971 Joint Oil Spill Conference Proceedings, Washington, D.C.

Godshall, F., W. Seguin, and P. Sabol, 1976. A statistical technique for the analysis and comparison of wind observation records. Appendix C, NOAA Technical Report EDS-17 GATE Convection Subprogram Data Center; Analysis of Ship Surface Meteorological Data Obtained During GAGE Intercomparison Periods.

Haight, F. J., 1942. Coastal along the Atlantic Coast. Coast and Geodetic Survey Special Publication 230. Washington, D.C.

Jelesnianski, C. P., 1970. Bottom stress time history in linearized equations of motion for storm surges. Monthly Weather Review, Vol. 98, pp. 469-478.

Meserve, J. M., 1974, U.S. Navy Marine Climatic Atlas of the World, Vol. 1, Washington, D.C., U.S. Government Printing Office.

Milgram, J. H., 1977. Mass transport of water and floating oil by gravity waves in deep water. Unpublished manuscript, Massachusetts Institute of Technology.

Smith, Cragg L., 1974. Determination of the Leeway of Oil Slicks," Department of Transportation, U.S. Coast Guard, Report No. CG-D-60-75.

Smith, Richard A., James R. Slack, and Robert K. Davis, 1976. An oil spill risk analysis for the North Atlantic outer continental shelf lease area. U.S. Geological Survey Open-file Report 76-620, 50 pp.

Sverdrup, Johnson, and Fleming, 1942. The Oceans: Their Physics, Chemistry and General Biology, Prentice Hall, New York.

Tully, Paul R., 1969. Removal of Floating Oil Slicks by the Controlled Combustion Technique, Oil on the Sea, Plenum Press.

U.S. Naval Weather Service Command, 1970. Summary of Synoptic Meteorological Observations (SSMO) for North American Coastal Marine Areas, Vol. II: Areas 4, Boston, 5, Quonset Point, 6, New York, and 7, Atlantic City, National Technical Information Service, AD 707 699.

3. INVESTIGATIONS OF CHEMICAL PROCESSES

3.1 Basic Chemistry of Spilled Oil

The phrase "spilled oil" encompasses a wide variety of hydrocarbon blends, including among others, crude oils, home heating oil, and heavy residual fuels. Crude oils and petroleum products contain thousands of individual chemical compounds, with a wide range of physical and chemical properties. When spilled into the aquatic environment, light distillate fuels, such as gasoline or jet fuels, do not behave in the same manner as do heavy distillates or heavy residual (No. 6) fuels. The light fuels spread to cover a large surface area with a thin film of oil, while the heavy fuels tend to thicken and form "pancakes" of oil up to several inches thick. Natural degradative processes are directly related to surface area of the slick, and therefore remove oil from the sea surface much more rapidly in the case of light oils than in the case of heavy products or crude oils.

Knowledge regarding the degradation of oil in the marine environment is limited. We know what the major degradative processes are, i.e., those natural processes that operate to modify the physical and chemical characteristics of spilled oil, changing its viscosity, solubility, toxicity, and so on. But we cannot predict the rate at which a No. 2 fuel oil will enter the water column under a given set of conditions. If "oil" were pure benzene or hexane, for example, then it would be a straightforward task to develop a set of physical-chemical descriptors, or mathematical algorithms, which would enable us to predict the behavior and fate of such "oil" under all possible environmental conditions. Unfortunately, such is not the case. One problem associated with the multicomponent nature of petroleum is a phenomenon known as "skinning." When oil forms thick lenses, from a centimeter to several inches thick, the evaporation of volatile components through the top surface (the air-oil interface) depletes the surface of the oil in light hydrocarbons, leaving behind heavier compounds characteristic of heavy fuel oils and asphalts. These high-molecular-weight compounds form an essentially impermeable skin at the air-oil interface, precluding continued evaporation of the lighter fraction from the interior of the oil lenses. This "skin" may be broken up with sufficient turbulence, and the process of evaporation can then restart. "Skinning" is only one of the many physical-chemical processes that take place with increasing age of an oil slick. Processes considered under the collective appellation of "chemical" include: (1) interactions with suspended sediments; (2) evaporation; (3) dissolution; (4) emulsification; (5) photo-oxidation; and (6) microbial degradation. The individual processes are not completely independent, photo-oxidation enhances the dissolution of the aromatic fraction of oil by the formation of more soluble carboxylic acids, and so on. Brief summaries of each of the major processes are presented below.

3.1.1 Suspended Sediments

During the Santa Barbara Channel blowout in 1969, an unusually large influx of suspended clay minerals from the Ventura and Santa Clara Rivers served to sink the oil on contact. A 1966 collision, involving the tanker

Anne Mildred Brøvig, released 125,000 barrels of crude oil to the North Sea almost instantaneously, but by the time local authorities had mobilized to deal with the spill the oil was dissipating rapidly. The disappearance of the oil was undoubtedly due to sinking. Whether it was the combination of cold February weather and the high specific gravity of Iranian crude, or interaction with suspended sediments, is not known, but little environmental damage was recorded as a result of the accident. Evaporation of volatile components of the No. 6 fuel oil released in the collision of the *Arizona Standard* and the *Oregon Standard* under the Golden Gate Bridge in January 1971 resulted in an increase in specific gravity of the remaining oil, allowing rapid dispersion of oil throughout the water column. How much of this process was due to unaided sinking, and how much could be attributed to interactions with the heavy suspended sediment load of San Francisco Bay, is not clear. In the 1970 *Arrow* accident in Chedabucto Bay, Nova Scotia, a spill of 65,000 barrels of No. 6 fuel oil in rough, cold seas, investigators found suspended oil particles (5 microns to 1 millimeter in size) widely distributed in the water column as far as 250 kilometers away from the wreck. Forrester (1971) estimated the flux of emulsified and particulate oil into the water column at 40 to 50 barrels per day for the first 15 days after the *Arrow* grounding.

The interaction of oil with suspended sediments is an important dissipative process, as the sinking of the *Anne Mildred Brøvig's* cargo and the Santa Barbara Channel spill show. There are two major classes of suspended particulate matter in which a distinction has to be made regarding the type of interaction that takes place with <u>dissolved</u> hydrocarbons. The first includes clay minerals of the kaolinite or montmorillonite type (water layers alternating between aluminosilicate layers), which swell when exposed to water or hydrocarbons, and easily accommodate bilayers of hydrocarbons between aluminosilicate sheets (<u>ab</u>sorption). The second type of suspended sediments includes such materials as SiO_2, $CaCO_3$, and other nonporous solids. On these materials, dissolved hydrocarbons can be <u>ad</u>sorbed. Obviously, adsorption on nonporous solids will not remove much oil from the water column, and thereby allow more oil to diffuse in, unless there is a high density of finely divided particles in the water column. The effects of suspended particulate matter become much less obvious when one considers (1) oil micelles interacting with particles, (2) collision between suspended particles and the slick itself, and (3) the coalescence of particles that have become coated with oil. These three processes, as nature would have it, are of primary importance in the interactions of oil with suspended sediments, yet we know little or nothing about these processes.

3.1.2 Evaporation

Evaporation from an oil slick is responsible for the loss of about one-fourth of most crude oil spills, representing those components that volatilize at temperatures below approximately 270°C. The principal difficulty in predicting evaporation is that it cannot be done for actual oil spills for more than a short period of time, because of the multicomponent nature of petroleum. Even for such light materials as No. 2 fuels and gasoline, mass transfer within the liquid phase will determine the rate at which certain volatile components will reach the oil-air interface, and as the spill is depleted in its more volatile components, the rate of evaporation will decrease as evaporation proceeds. For a heavy residual fuel oil, such as No. 6, evaporation plays only a minor role, and is limited to its effect on the light "cutter stock" often added to straight-run No. 6 to improve its handling characteristics.

3.1.3 Dissolution

True thermodynamic dissolution of petroleum hydrocarbons is not a significant contribution to the mass transfer of oil from the surface into the water column. The most volatile portions of crude oils and light distillate fuels are also the most soluble, but rarely would one expect to find a significant downward flux of oil due to dissolution. In terms of toxicity, however, the dissolved light hydrocarbons present a great environmental hazard. Making the distinction between true "dissolved" and colloidal or supracolloidal hydrocarbon "droplets" in the water column is a difficult problem even in the best of laboratory situations. Suffice it to say, for the moment, that it is not unreasonable to lump the true dissolved fraction of oil with the oil-in-water emulsified oil, discussed in the next section, and the other forms of oil that are worked into the water column by one mechanism or another.

3.1.4 Emulsification

Oil can form either micellar oil-in-water (o/w) emulsions, or water-in-oil (w/o) emulsions. Micelles are colloidal aggregates of the lipoidal (oil) phase suspended in the aqueous phase. Micelle formation is "good" from a dissipation point of view, since the micelles are microscopic in size and are readily distributed through the water colum. Their microscopic size, incorporating perhaps only a hundred hydrocarbon molecules per micelle, provides much more surface area than could be available at the underside of a continuous oil slick, promoting degradation of o/w emulsions by microbial oxidation. The w/o emulsions, known as "mousse," are a very different problem, as they float and agglomerate into large masses. Such w/o emulsions can cause fluid oils to become viscous, as well as cause viscous oils to become fluid. Neither result is beneficial, as the product is an emulsion with the consistency of melted Hershey's chocolate, whether one begins with gasoline or with asphalt. "Mousse" is fluid enough to coat shorelines thoroughly, yet viscous enough to substantially retard evaporation. In the 1967 *Torrey Canyon* accident, the crude oil formed "mousse" before reaching shore. In the 1975 Key West oil spill, a solvent-based detergent was added to the oil before it was pumped over the side, producing a 60/40 w/o emulsion. During the *Arrow* spill in Chedabucto Bay, and in the 1969 West Falmouth spill, mousse did not form, although in the latter two accidents oil was mechanically driven into the water column and, in the West Falmouth spill at least, into the sediments.

3.1.5 Oxidation

Oxidation of an oil slick enhances the dissolution rate of the oil and produces surfactant molecules that will promote emulsification. There are three major oxidative mechanisms to consider: photo-oxidation, auto-oxidation, and microbial oxidation. Betancourt and McLean (1973) examined the oxidative degradation of the No. 6 fuel oil from the *Arrow* spill, noting that the original cargo from the *Arrow* contained 2.28% sulfur and that after 20 months of onshore weathering the sulfur content had dropped to 1.45%. Since the sulfur-containing components of oil are generally not considered to be volatile, the conclusion one arrives at is that sulfur-containing compounds are preferentially oxidized during weathering.

Many investigators have contributed to our knowledge of microbial degradation of oil, such phenomena having been the subject of several investigations since the 1920's. Numerous organisms have been identified that can use hydrocarbons as both an energy and as a carbon source, but the process of biodegradation of oil is extremely complex. It may seem surprising at first to read of the variety of hydrocarbons that can serve as "food" for microorganisms, from methane to asphalt, but were it not for the adaptability of these organisms oil from natural seepages might well have covered the earth's surface to a depth of several centimeters by now.

Microorganisms are able to convert hydrocarbons into more soluble alcohols, organic acids, and into CO_2 and water via enzyme-catalyzed reactions. For aerobic metabolism of a simple hydrocarbon, the oxidation reaction is represented by the reaction:

$$C_nH_{2n} + (3/2)nO_2 \rightarrow nCO_2 + nH_2O.$$

If the organism consumed all the available hydrocarbon for energy purposes, the ratio of CO_2 produced to O_2 consumed should equal 0.67. This ratio, called the respiratory quotient, was examined in 1942 by Stone et al. for mixed soil bacteria. They found values of the respiratory quotient as low as 0.12 for heavy fractions of crude oil, and as high as 0.64 for refined motor oil. Also in 1942, Johnson et al. measured respiratory quotients for Bacterium alphaticum of 0.47 for heptane, 0.48 for octane, and 0.63 for nonane and dodecane. Anaerobic oxidation of hydrocarbons can occur with either nitrate or sulfate taking the place of oxygen as the electron donor. Anaerobic oxidation of hydrocarbons is usually incomplete, leaving the hydrocarbon in some partly oxidized state rather than as CO_2 and water.

The biological conversion of a pure hydrocarbon to a more water-soluble alcohol or acid assists in the removal of petroleum hydrocarbons from the sea surface. Since most of the hydrocarbon-utilizing organisms are not lipoidal, the microbial oxidation of an oil slick is restricted to the aqueous side of the water/oil interface. The increased solubility of the partly oxidized intermediates by this process allows for transfer of some of the oil away from the interfacial region. Beerstecher (1954), based on measurements at room temperature, reported rates of crude oil oxidation of 1.2 to 1.5 g $m^{-2}d^{-1}$, and for refined oil of about 0.5 g $m^{-2}d^{-1}$.

There have been a number of investigations into the effect of the molecular properties of the substrate on the rate of microbial oxidation of petroleum hydrocarbons. In general, it can be said that the longer-chain aliphatic hydrocarbons are more easily degraded than short-chain compounds, though it may sometimes be difficult to provide adequate dispersion of long-chain paraffins to allow for the maximum rate of degradation. Also, branched chain hydrocarbons are utilized preferentially over their straight-chain isomers. Unsaturation in a hydrocarbon offers a site for immediate hydrolysis, and as such encourages microbial oxidation. Multiply unsaturated compounds such as butadiene are rapidly oxidized, but they do not occur in crude oil. Aromatic compounds are attacked quite readily, possibly because there are much more water-soluble than aliphatic compounds of comparable molecular weight. The addition of side-chains to an aromatic compound facilitates microbial oxidation, as does increasing molecular weight.

The mechanisms by which spilled oil is transported away from the surface of the ocean are complex and poorly understood. A major facet of the continuous study of accidental oil spills must of necessity be the sampling and analysis of the oil itself, the water column beneath the oil slick, and the sediment/water interface, which is often the ultimate sink of "weathered" oil. Such investigations were undertaken by the several groups involved in the short- and medium-term assessment of the fate of the *Argo Merchant* oil.

There are numerous mathematical models in existence that attempt to describe the transport of oil in the marine environment. Most of these models are limited to two-dimensional spreading and advection at the sea-air interface. Understanding the physical and chemical transformations that oil undergoes when spilled in the marine environment is an important facet in developing three-dimensional oil spill models that will accurately predict the transportation and concentrations of oil in the water column, and ultimately to the sediments and littoral regions. For this reason, samples of oil were collected from the *Argo Merchant*, from the slick, the water column, and the sediments beneath the slick. All the samples were initially screened at the USCG Research and Development Center by ultraviolet fluorescence and thin-layer chromatography to determine the amount of oil present. Selected samples have been sent to the NOAA's National Analytical Facility in Seattle, Washington, for gas-chromatographic-mass spectrometric (GC-MS) analysis. It is the goal of this research effort to determine the extent to which the *Argo Merchant* oil entered the water column as well as the sediments during and immediately after the spill.

3.2 Oil Sampling

One of the technical problems associated with the *Argo Merchant* oil spill was the initial lack of reference samples of the cargo oil and bunker fuel carried by the vessel. There are still no reference samples of the latter. Two dirrerent No. 6 fuels were carried as cargo: 50,000 barrels of one, and 139,000 barrels of other. The only oil sample withdrawn directly from one of the cargo tanks was a 16-ounce sample taken from the No. 4 port tank by J. H. Milgram of the Massachusetts Institute of Technology (MIT) on December 19, 1976. Other samples of oil were taken from the slick on several different occasions, as described below, but no samples were taken from the *Argo Merchant* other than the one obtained by Milgram. Since the viscosities of the two cargoes were reported to be nearly identical, it is hoped that despite the lack of samples from the second, they may have differed only in their relative proportions of "cutter stock."

P. Fricke of Woods Hole Oceanographic Institution obtained 5 gallons of "surrogate" *Argo Merchant* oil on February 5, 1977, from a tanker in Boston harbor. This "surrogate" oil was No. 6 fuel oil from the same refinery and had undergone the same refining process as the oil carried by the *Argo Merchant*. Samples have been made available to all cooperating investigators for further studies.

In addition to the surrogate sample, P. Fricke is trying to arrange for samples of the two actual *Argo Merchant* oils to be shipped from the refinery in Venezuela within a few months. Because of the apparent fractionation of lighter components of the *Argo Merchant* oil into the water column, it will also be necessary to obtain a reference sample of the "cutter stock," which was used for improving the handling characteristics of the tanker's cargo, before accurate oil-in-water concentrations can be reported. Fricke is attempting to obtain such a sample also.

3.2.1 Oil Slick Sampling and Analyses

Samples

Samples that have played a significant role in the analysis of the fate of the *Argo Merchant* oil slick include: (1) surface samples taken by J. H. Milgram on December 17 and 19, 1976, within 1 mile of the tanker, and (2) a surface sample taken with a bucket lowered from a helicopter on December 19 near the "head" end of the horeseshoe-shaped slick. The first samples were 12- to 24-hours old according to Milgram's estimate. The second sample was taken on December 19 by J. Galt and J. Mattson of NOAA at 41°04.0'N latitude, 69°18.2'W longitude, and was probably 2 to 3 days old. On December 23, S. Fortier of the USCG Research and Development Center took three surface slick samples from a helicopter. These samples are stored at the Center. On December 25, the USCGC *Vigilant* obtained a sample from the large pancake of oil sighted that day, and that was the last surface slick sample collected from the oil spilled by the *Argo Merchant*. Part of the last sample is held by Milgram at MIT.

Physical properties

Analyses of the surface slick samples as well as of the sample taken directly from the *Argo Merchant* were performed by Milgram and by J. Quinn of the University of Rhode Island. The physical properties reported by Milgram for the cargo sample and the "thick" surface slick sample he obtained on December 19 are listed in Table 3-1.

In addition, Milgram subjected the cargo sample to atmospheric distillation, noting that 20% of the cargo sample distilled off at temperatures below 120°C, undoubtedly representing the light distillate "cutter stock"

Table 3-1. Physical properties of cargo oil sample from No. 4 port tank and "thick" slick sample taken on December 19 (J. H. Milgram, MIT).

Property	Cargo sample	Slick sample
Specific gravity	0.96	0.96
Surface tension	35 dynes/cm	35.5 cynes/cm
Viscosity, @ 10°C	33,298 cp	71,977 cp*
Pour point, ASTM D97-66	2°C	2°C

* The slick sample contained about 4% water, affecting the viscosity measurement.

that is normally added to straight-run No. 6 fuel oil to improve handling characteristics. The 2°C pour point is another indication of the substantial fraction of cutter stock present in the cargo oil. An important observation, made by Milgram early in the spill, was that the specific gravity of the residue remaining after distillation to 210°C also exhibited a spevific gravity of 0.96. This was an early indication that the oil was not going to sink of its own accord, even after prolonged weathering.

Milgram also measured the surface tension of water pipetted from beneath a thin film of oil, obtaining a value of 79 dynes/cm, as well as the surface tension of water with a thin oil film on top, at 59 dynes/cm. The pour point reported above is the "upper pour point" as defined by ASTM D97-66, and is measured by (a) placing oil in a 1-inch diameter tube, (b) warming it up to dissolve waxy components, and (c) then cooling it and measuring the temperatures at which the oil does not move for 5 seconds, with the tube held horizontally. Adding 3°C to the final temperature gives the "upper pour point." Milgram notes that although the oil did not move for the required 5 seconds, it would begin to flow before 10 seconds had elapsed.

On December 22, Milgram gave aliquots of his December 19 samples to R. Sexton of the University of Rhode Island. On December 23, these samples were analyzed by gas chromatography by J. Quinn, URI, according to the following procedure.

<u>Chemical analysis by gas chromatography</u>

Two drops of each sample was transferred to 10-milliliter pear-shaped flasks using Pasteur pipettes, and two drops of CS_2 were added to dissolve the oil. Each sample was injected into a 5711 gas chromatograph under the conditions listed in Table 3-2. A standard hydrocarbon mixture was injected for identification of the peaks in the chromatograms, which are shown in

Table 3-2. Gas chromatograph conditions used by J. Quinn, URI

Condition	Specification
Column	4% FFAP, 2 m x 2.2 mm inner diameter, stainless steel.
Temperature program	75°C to 250°C at 8°C/min and hold.
Chart speed	0.25 in./min.
Detector temperature	300°C.
Injection port temperature	250°C.
Range and attenuation	4×10^2.
Amount injected	2 to 3/ul.

Figures 3-1 and 3-2 for Milgram's two samples. The cargo sample is represented in Figure 3-1, and Figure 3-2 represents the slick sample obtained on December 19 within 1 mile of the *Argo Merchant*. The presence of C_{10}-C_{16} n-alkanes in the two samples corroborates Milgram's analysis of 20% light fuel oil in the cargo, and is consistent with the results obtained by R. Jadamec of the USCG Research and Development Center, which are discussed in the next section.

3.2.2 Water Sampling and Analyses

Samples

Water samples obtained after the *Argo Merchant* grounding included the first taken during the WHOI R/V *Oceanus II* cruise on December 20 and 21 and those obtained on the cruise of the URI R/V *Endeavor*, February 8-12. Other vessels involved in water sampling were the USCGC's *Evergreen*, *Vigilant*, *Bittersweet*, and NOAA's *Delaware II*. The sampling locations are plotted in Figure 3-3; further details are given in Appendix V.

By far the largest number of samples were taken with Sterile Bag Samplers (Model 1030, General Oceanics, Inc., Miami, Florida). This sampler is designed to be lowered through the sea-air interface while sealed, opened by messenger at depth, and automatically closing before being returned to the surface. The sample of approximately 1 liter thus obtained is uncontaminated by a surface oil slick, and is representative of the subsurface water. In areas thought to be uncontaminated, additional samples were taken with standard Niskin bottles of the type that passes through the air-sea interface in an "open" configuration and is closed at depth by a messenger.

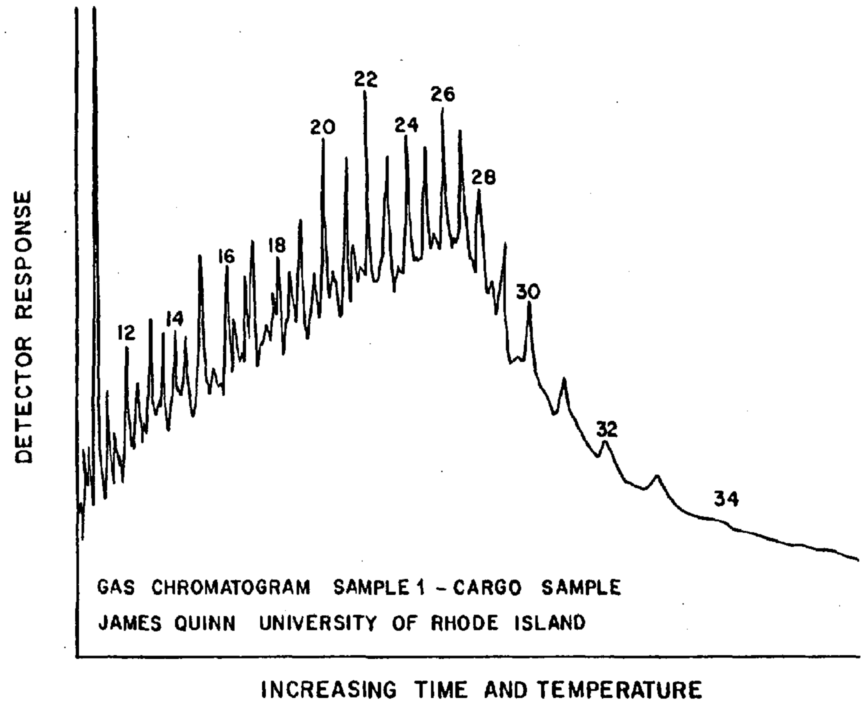


Figure 3-1. Gas chromatogram of *Argo Merchant* cargo sample.

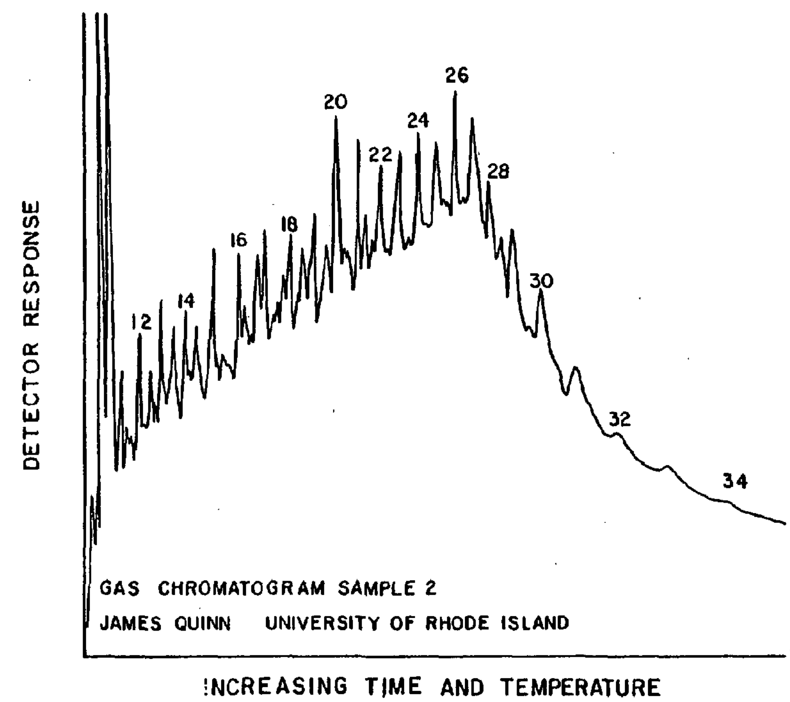


Figure 3-2. Gas chromatogram of oil sample taken from slick within 1 mile of the *Argo Merchant* by J. Milgram on December 19.

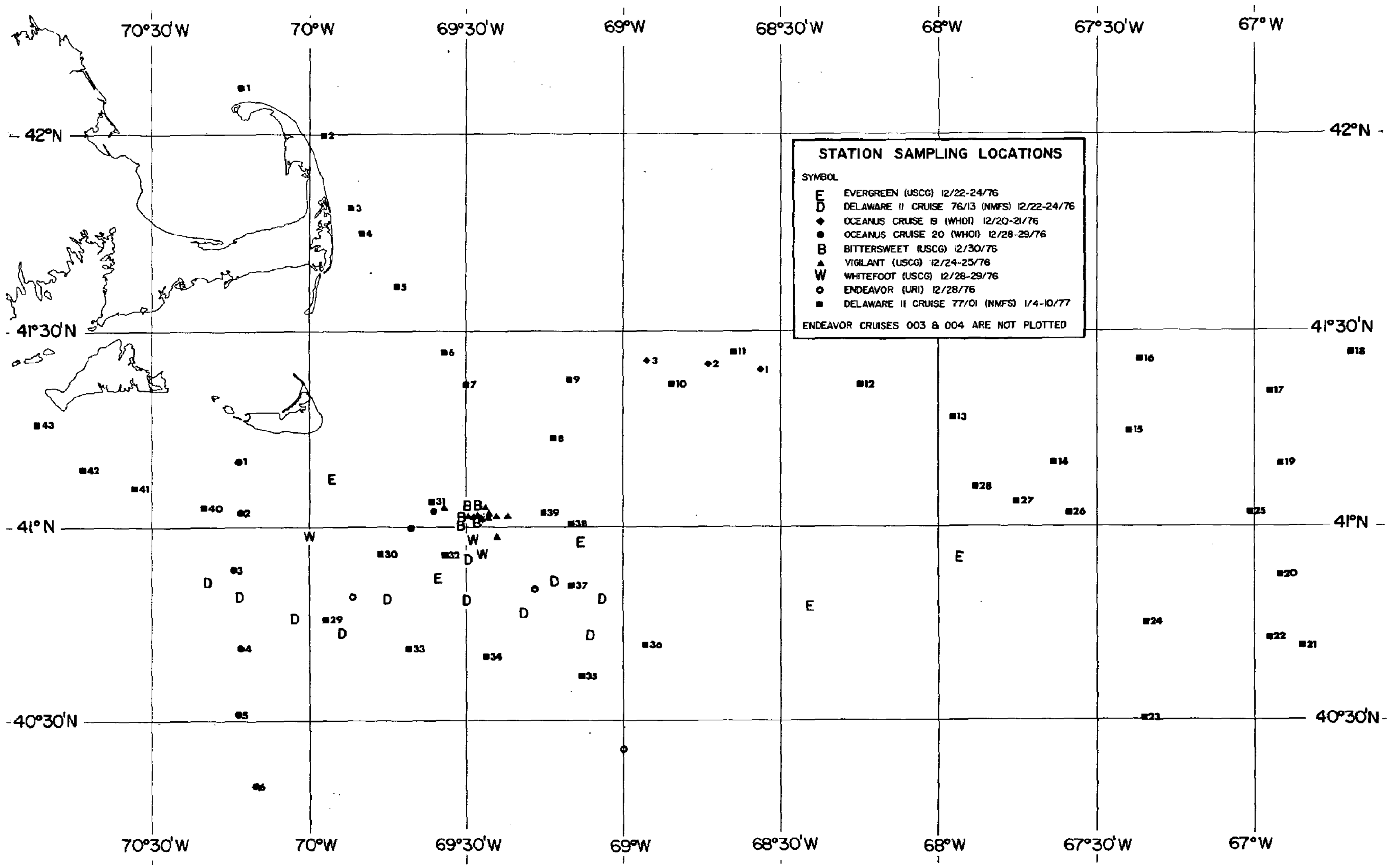


Figure 3-3. Water sampling locations.

All water samples were either immediately frozen, or were extracted with hexane aboard ship (on the later *Endeavor* cruises) in order to stabilize any hydrocarbons contained within against bacterial degradation. Frozen samples were transported, using a completely documented chain of custody, by G. Heimerdinger, NOAA Liaison at Woods Hole Oceanographic Institution, to the USCG R&D Center at Groton, Connecticut. The water samples were then extracted and prescreened for petroleum hydrocarbons (PHC) by R. Jadamec of the Center.

A Chemical Analysis Committee, formed at a meeting at Woods Hole, January 3-4, 1977, is monitoring the continuing analyses of all water samples.

Ultra-violet fluorescence screening of water samples

By this procedure, one liter of sample is extracted twice, using 10-milliliter portions of spectroquality hexane. The two hexane extracts are combined and then analyzed by synchronous scanning ultraviolet fluorescence. The excitation and emission monochromators are initially set at 255 and 280 nanometers, respectively. The continuous excitation-emission spectrum is recorded until final settings of 475 and 500 nanometers on the excitation and emission monochromators, respectively, are obtained. The resulting fluorescence spectrum reveals the distribution of the polyaromatic rings present in the sample. Comparison of the sample spectrum with that of the reference oil spectrum, obtained at various concentration levels, will indicate the relative concentration of oil present in the sample. The sample taken from surface slick by Galt and Mattson on December 19 is being used as the reference oil.

The screening of water column samples is still in progress. Analyses of samples collected by the USCGC's *Bittersweet*, *Evergreen*, and *Vigilant* directly beneath the slick indicate very low levels of PHC concentration. All water samples analyzed indicate an absence of high-molecular-weight polyaromatic hydrocarbons at various depths beneath and around the slick from December 20 through December 31. The absence of 4- and 5-ring polyaromatic compounds in the water makes it difficult to use the whole oil as a concentration standard. As a temporary compromise, the 2- and 3-ring portion of the whole oil spectrum was employed as the concentration reference. The error this introduces is one of slightly overestimating the amount of oil present in the water column samples. Using this method of calibration, as well as calibrating against the API "pool" No. 2 fuel oil (available from the Biology Department, Texas A&M University), the highest petroleum hydrocarbon (PHC) concentrations measured were approximately 250 parts per billion. These were found in samples taken beneath the slick by the USCGC's *Vigilant* and *Bittersweet*. Samples on these cruises were taken at two depths ranging from 1 to 10 feet below the surface. It is in the deeper of the two samples that the highest concentrations were found according to R. Jadamec. It is the consensus of the chemical analysis committee that the oil observed in the water samples is actually the "cutter stock," which represents about 20% of the cargo oil. An effort is being made by P. Fricke of WHOI to obtain an authentic sample of this "cutter stock." When a sample is obtained, the water column samples will be corrected to it as a new standard.

Samples taken during the January 26-29 and February 8-12 *Endeavor* cruises included water samples taken at the surface, at a depth of 6 meters, and near the bottom, as well as bottom sediment samples at each station. The near-bottom and sediment samples will be carefully analyzed to see if there is any relationship between sediment PHC's and PHC's in the water column. The water samples taken on both *Endeavor* cruises show a lower hydrocarbon content than that observed in samples obtained from the *Evergreen*, *Bittersweet*, and *Vigilant* directly beneath the slick. In all cases, only the light aromatic fraction of the *Argo Merchant* oil could be detected, if indeed it was *Argo Merchant* oil at all. Representative samples of water column extracts are being selected for additional GC-MS analysis at the NOAA National Analytical Facility in Seattle, and several samples will be archived for eventual intercalibration with BLM's "benchmark" survey contractors for the Georges Bank lease area.

"Total extractable organics" from *Endeavor* samples

On *Endeavor* cruise EN-002, December 28-30, C. Brown of URI analyzed six water samples by infrared spectrometry for "total extractable organics." The cruise track and station locations are shown on Figure 3-4, where the "X" marks the location of the *Argo Merchant*. Stations 1 and 3 were well removed from the area of surface oil contamination, and any discovery of oil in those water samples would not be expected to have originated from the grounded tanker. Station 2 was well within the area subject to nearly continual surface contamination since December 19, and could have been expected to exhibit some PHC contamination in the water column. Water samples were taken at the surface at all three stations, at a depth of 6 meters at stations 1 and 2, and at the bottom (39 meters) at station 1. All six samples were extracted with CCl_4 by Brown's group at URI, and analyzed for "total extractable organics." At Station 1, they measured concentrations of 68 and 29 parts per billion, respectively, for the surface and 6-meter samples, values that are not indicative of any unusual amount of contamination. The bottom water sample at Station 1 yielded a value of 191 parts per billion, higher than Brown could expect for the area, possibly because the bottom was disturbed during the sampling.

At stations 2 and 3, the surface "total extractable organics" concentrations were 47 and 435 parts per billion, respectively, and the 6-meter sample at station 2 showed a concentration of 455 parts per billion. This last sample could have included oil from the *Argo Merchant*, and Brown subjected this sample, plus the surface sample from station 3, to further analyses.

The hydrocarbon concentrations revealed in the two samples by gas chromatography were also high, but were not significantly different from the types and amounts found in the "clean" samples. Brown suspects that the high values of total extractable organics in the two samples therefore are due to soluble species rather than PHCs. Further analysis by infrared spectroscopy of the 6-meter sample from station 2 indicated the presence of two organic species: phthalic acid esters and an unidentifiable species. They tried to determine whether these compounds may have originated by degradation of *Argo Merchant* oil but so far this has not been confirmed by laboratory

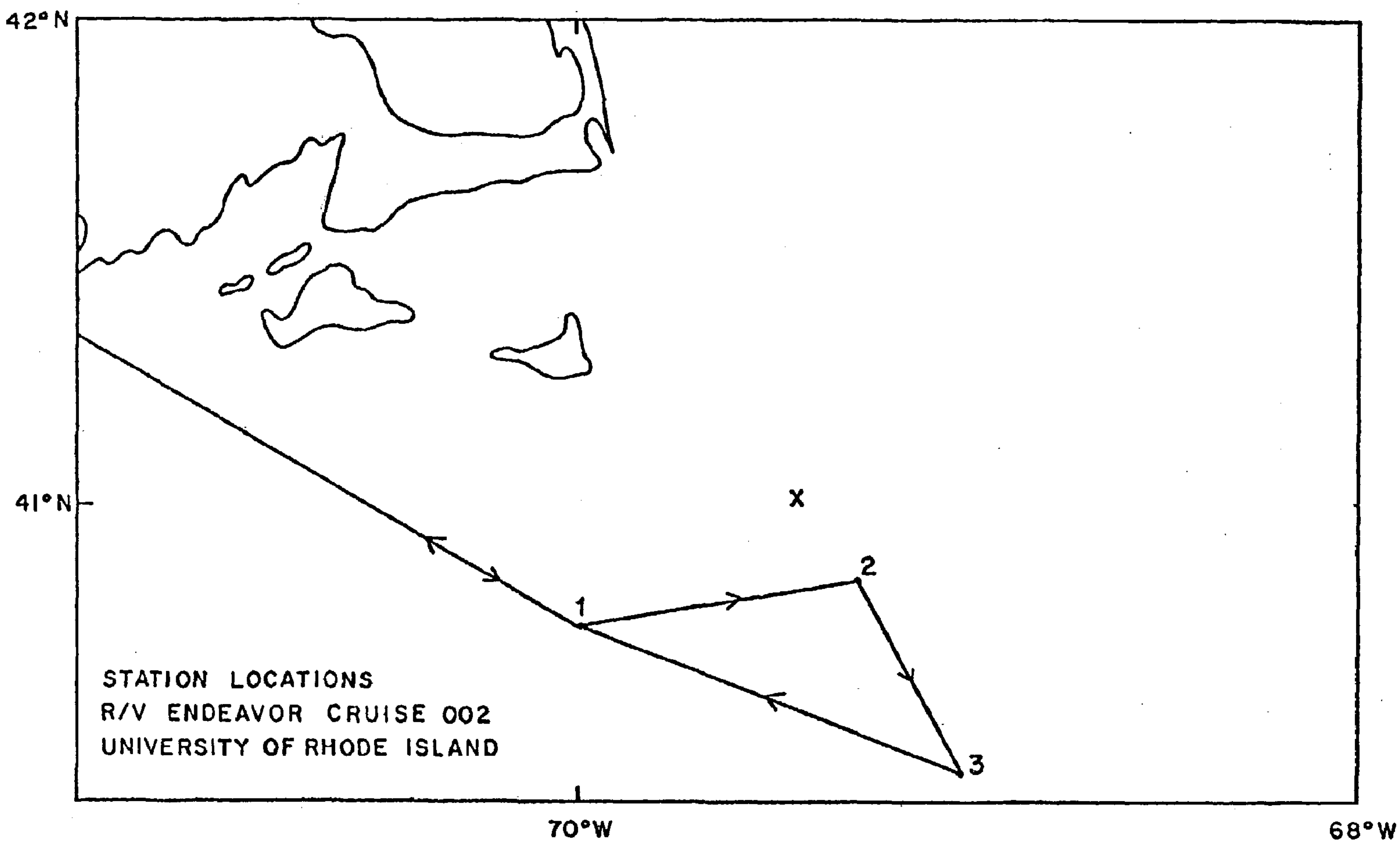


Figure 3-4. Stations where samples for total extractable organics were taken during *Endeavor* cruise 002.

experimentation with *Argo Merchant* oil. It is conceivable that these compounds were formed by biodegradation of the oil and cannot be simulated in the laboratory.

J. Quinn of URI analyzed the two sediment samples from *Endeavor* cruise EN-002 for total hydrocarbons by gas chromatography (FFAP) columns, after isolation of hydrocarbons by thin-layer chromatography. He found 0.7 parts per million total hydrocarbons at station 1, and 3.0 parts per million at station 2, based on sediment dry weight. However, Quinn reports that *Argo Merchant* oil was not detected in these samples. The two sediment samples were also extracted with CCl_4 by Brown, and the amounts of "total extractable organics" measured by infrared spectrometry. At station 1, 15 parts per million (wet weight) was found, and at station 2, 9 parts per million. These values are typical of "clean" sediment, and bear no relation to the values reported by Quinn for "total hydrocarbons."

Droplet size analysis at URI

Oil can be dispersed into the water column by breaking waves. This is an important phenomenon and is affected by the surface chemistry of the oil and water. In some instances the oil droplets are small enough to remain suspended for so long that the suspension can be considered permanent (until the oil is degraded) and in others the suspension is transitory. In the case of the *Argo Merchant* it is certain that in the rough weather oil droplets were driven down into the water column by breaking waves and some, or all, of these droplets quickly rose back to the surface. Whether or not a substantial number of semipermanent tiny droplets were driven into the water is still an open question.

P. Cornillon of the Department of Ocean Engineering at URI also analyzed the water samples from *Endeavor* cruise EN-002. His objective was to obtain the particle size distribution of oil droplets as a function of latitude, longitude, and depth in the water column. The presence of such particles in the water column had been a major feature of the *Arrow* grounding in Chedabucto Bay, Nova Scotia, in 1971 (Forrester, 1971). Cornillon hoped to obtain some idea of what is involved in the entrainment process; specifically, if oil droplets were discovered, whether they contained sediment or water or were composed entirely of oil. To this end, water from *Endeavor* cruise EN-002 was filtered through a Millipore filter with a pore size of 0.45 microns. The filters were refrigerated and analyzed under a microscope.

The entire filter was scanned under a microscope at a magnification of 50, using reflected light. Any object that remotely resembled oil was treated with carbon tetrachloride to dissolve the oil, and the object was then reexamined for any change. One of the samples, the 6-meter sample at URI station 2, was also scanned at magnification of 100 with reflected light and at a magnification of 50 with transmitted light.

The results of these analyses to date are given in Table 3-3. Only the surface sample taken at station 3 showed oil droplets larger than 10 microns in size, and that was a single, large droplet. To complete this analysis, each of the filters has yet to be scanned with a magnification of 50 using transmitted light. Also, the smallest resolvable droplets will be determined for each filter to obtain a lower limit in resolving power.

Table 3-3. Droplet distribution analysis of *Endeavor* cruise 002 water samples (Cornillon URI)

Station No.	Depth of sample (meters)	Sampling method	Volume filtered (liters)	Oil observed	Remarks
1	18	Plankton	-	-	Too much particulate matter
1	1	Niskin	0.85	No	No oil particles >10 microns
1	6	Niskin	1.10	No	High sediment load, no oil >10 microns
1	39	Niskin	0.80	No	High sediment load, no oil >10 microns
2	6	Niskin	1.10	No	Some sediment, no oil >5 microns
2	0	Bucket	1.00	No	Some sediment, no oil >microns
3	0	Bucket	1.50	Yes	Some sediment, one oil droplet 155 x 300 microns

3.2.3 Sediment Sampling and Analyses

A large number of sediment samples were taken from the *Evergreen*, *Oceanus*, *Delaware II*, and *Endeavor* during the last two weeks of December, but for a variety of purposes and by different sampling procedures. At the meeting at Woods Hole on January 3-4, 1977, all the cooperating investigators agreed that the sediment samples should be handled in the same way as the water samples, i.e., after extraction and prescreening by R. Jadamec at the Coast Guard R&D Center, selected samples were to be sent to the NOAA National Analytical Facility in Seattle for GC-MS analysis.

Sampling program

A chemical analysis committee, established at the Woods Hole meeting, continues to maintain control over the selection of samples to be subjected to further analysis. This committee consists of the following: James S. Mattson, NOAA (Chairman); Richard Jadamec, USCG R&D Center; William MacLeod, NOAA National Analytical Facility; John Farrington, Woods Hole Oceanographic Institution; James Quinn and Chris Brown, University of Rhode Island; Richard Feely, NOAA; Ed Myers, NOAA. All the samples that were in storage as of January 3, 1977, have subsequently been handled, as have all samples taken on *Endeavor* cruises 003, 004, and 005, according to the "chain of custody" guidelines issued by EPA Region I (directive signed by John McGlenon, July 5, 1973). G. Heimerdinger of NOAA met the *Endeavor* on each return to assume custody of the samples, and they have since been documented in accordance with EPA guidelines.

At the Woods Hole meeting in January, the subject of the immediate impact of the *Argo Merchant* oil spill was specifically addressed. This meet- chaired by R. Kolpack, University of Southern California, and Don Swift, Atlantic Oceanographic and Meteorological Laboratories, NOAA, resulted in the suggestions that investigators concentrate on benthic processes to determine the area where oil might be deposited in the bottom sediments. *Endeavor* cruise EN-003, with Eva Hoffman as chief scientist, was planned to carry out this objective (Appendix V). The cruise started on January 26, 1977, and was terminated by bad weather on January 29. A second cruise, EN-004, was conducted from February 9 to 12, 1977, to complete the initial survey. A third cruise was planned for February 21, 1977, to follow up on the findings of the second cruise.

The sampling program included the area thought to be affected beneath the surface slick, as well as marginal areas sufficiently beyond surface slick extensions to serve as partial controls. Also included were areas in the path of potential bottom sediment movement. In addition, the plan provided information about the bottom sediments and the near-bottom hydraulic regime (about 100 centimeters above the sea floor) in order to assess bottom transport processes.

The 27 sediment samples from *Oceanus* cruises 19 and 20 (Appendix V) 26 samples from *Delaware II* cruises 76-13 and 77-01 (Appendix V), 7 samples from *Endeavor* cruise EN-002, and 16 samples from the USCGC *Evergreen* (a total of 76 samples, representing 42 stations) were taken between December 20 and January 10. All these samples have been extracted and prescreened by R. Jadamec of the USCG Research and Development Center, and the results of these analyses are described later in this section.

The benthic survey cruises undertaken by URI on *Endeavor* cruises EN-003, 004, and EN-005 produced another suite of water column and bottom samples, which were taken under the guidelines developed at the Woods Hole meeting on January 3-4. Appendix V contains the cruise report for EN-003, during which *Endeavor* was able to occupy only five stations because of bad weather, and a cruise "report" for EN-004, when the URI vessel was able to largely complete the survey as planned. Appendix V contains a description of the sampling locations in the general area covered by the oil slick from the *Argo Merchant*. In summary, it was assumed by URI that the most likely to show significant quantities of oil would be:

(1) Areas covered by the slick for the longest period of time.
(2) Shallow areas.
(3) Areas covered by the slick when the sea state was high.

In addition, the remainder of the area covered by the slick (deeper areas and areas covered when the sea state was calm) would also be sampled. Two areas, designated "A" and "B" in Figure 3-5, were determined to have been covered by heavy oil concentrations for at least 6 days. Area A includes the site of the *Argo Merchant*. Area B is the area where the slick stalled for 6 days before moving eastward. URI investigators randomly selected 30 stations within the two areas: 6 in area A, and 24 in area B. In addition to these 30 stations, URI chose 3 stations in shallow areas (designated "C"); 3 that were covered by a heavy concentration of oil during high sea states ("D"); 2 that coincided with *Endeavor* cruise 002 stations 1 and 2 ("E"); and 2 stations located between areas A and B ("F").

Appendix V lists the positions of all the above stations, except those designated "G," which were chosen by the chief scientist during *Endeavor* cruise 004. And it is at two of these stations, G-42 and G-43, that oil has been determined up to date, as well as at stations A-40 and D-36 (figure 3-6).

Screening Procedures

Sediment samples are being screened by two methods: thin-layer chromatography, and ultraviolet fluorescence. Selected samples are then forwarded to the NOAA National Analytical Facility in Seattle for GC-MS analysis.

The ultraviolet fluorescence procedure developed by Gordon and Krisa (1974) is being used on both the water column and sediment samples to determine if substantial quantities of oil are present. The thin-layer chromatographic method was developed by Mississippi State University under contract to the U.S. Coast Guard.

Thin-layer chromatographic screening of sediments. A measured volume of sediment (5 cubic centimeters) is extracted with 2 milliliters of spectroquality hexane by stirring the slurry for 1 minute. The hexane is then decanted into a 5-milliliter vial and reduced in volume to 0.5 milliliter by gentle warming over a hot plate. Twenty-five microliters of the concentrated hexane extract is spotted on the active side of type 5A chromatographic paper strip approximately 1.5 centimeters above the bottom edge. The spot is allowed to dry thoroughly and then developed in a mixture of 35% petroleum ether and 65% benzene for 45 to 60 seconds. The chromatographic strip is allowed to dry and viewed under ultraviolet light. The presence of a blue fluorescent spot is indicative of the presence of oil. The greater the intensity of the fluorescence, the greater the quantity of oil. The minimum

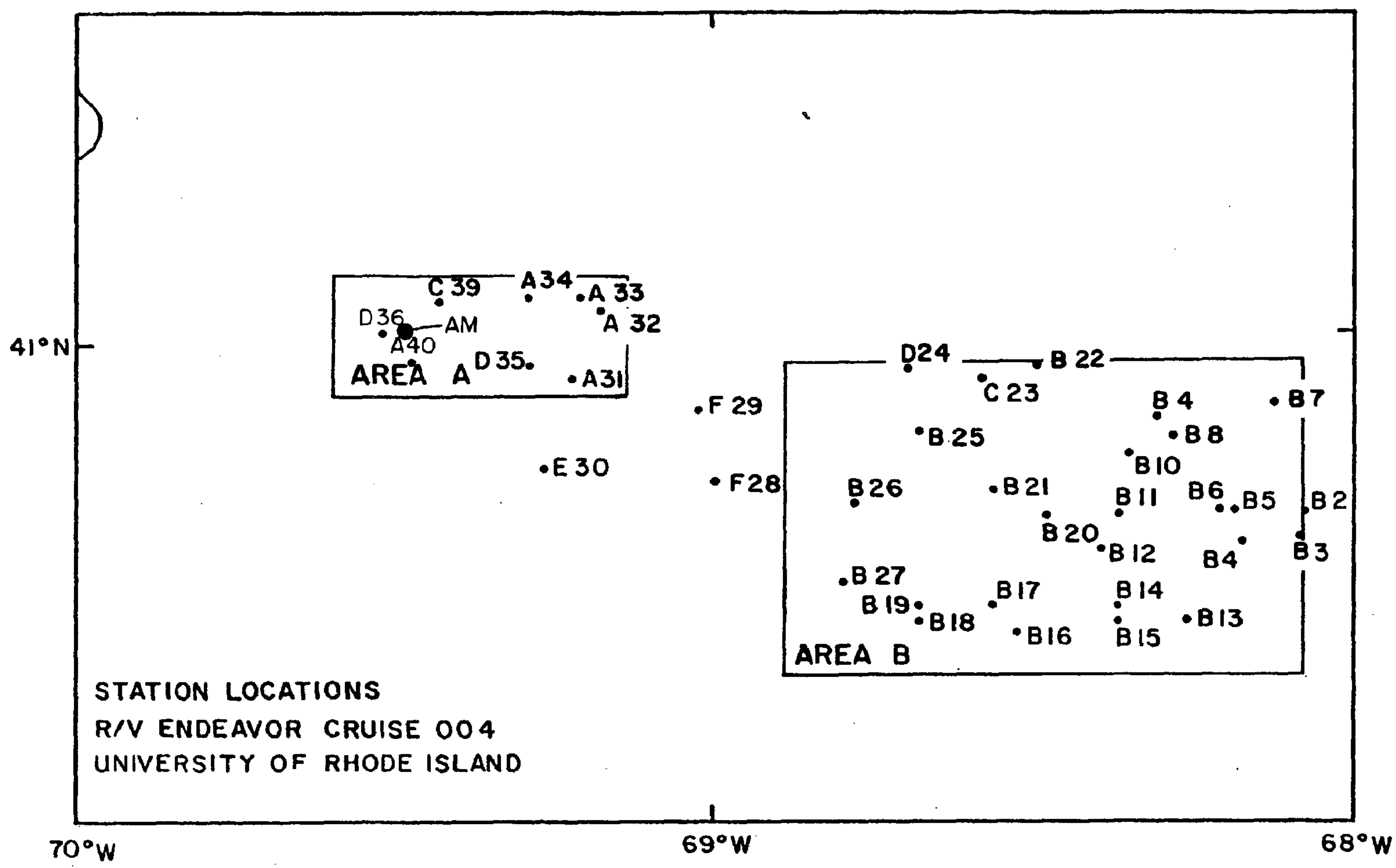


Figure 3-5. Sampling station locations for benthic survey conducted by the University of Rhode Island.

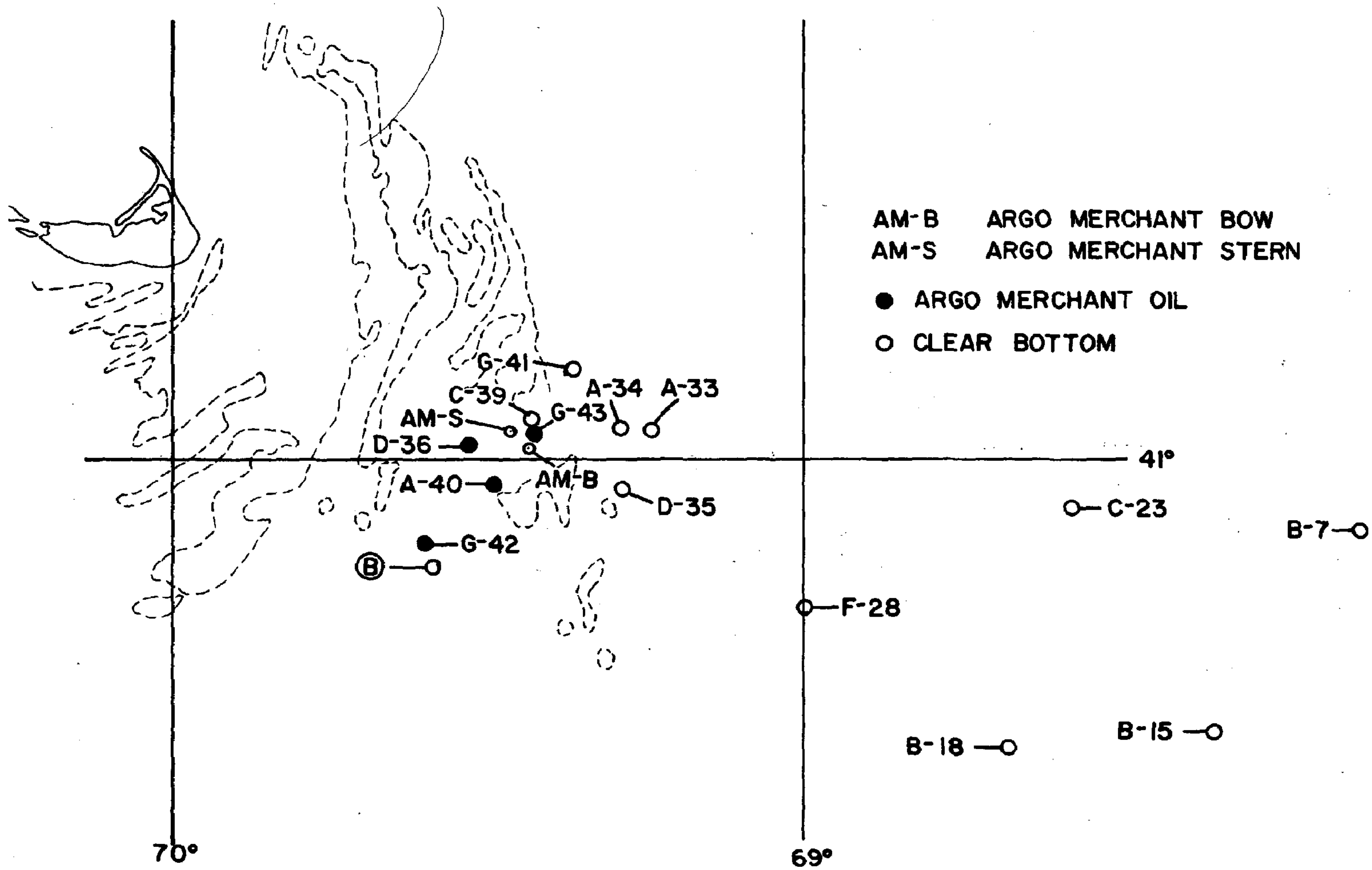


Figure 3-6. Preliminary results of sediment screening.

detectable level of fluorescences is equivalent to 2 micrograms of oil contained in 5 cubic centimeters of sediment.

Ultraviolet fluorescence screening of sediment samples. A measured volume of sediment (10 cubic centimeters) is extracted with 5 milliliters of spectroquality hexane by stirring the slurry for 1 minute. The extract is then removed and analyzed by the synchronously scanning fluorescence technique used for the water samples. Comparison of the sample spectrum with that of the reference oil spectrum at various concentrations indicates the relative concentration of oil present in the samples. The reference oil is the same as that being used for the water samples.

Preliminary Results

All sediment samples have been screened by the thin-layer chromatographic procedure. Samples collected on the *Evergreen, Delaware II* 76-13, and *Delaware II* 77-01 cruises indicate extremely low levels of petroleum concentrations, with a majority of these samples having no fluorescent blue spot. Sediment samples collected on *Oceanus* cruises 19 and 20 indicate substantially higher levels of petroleum concentrations than those obtained on the *Evergreen* and *Delaware II* cruises. The samples collected on *Oceanus* cruise 20 at stations 1 and 5 have the highest level of petroleum concentration. The PHC found at station 1 is a light distillate, while that found at station 5 is a heavy fuel oil that appears unrelated to the *Argo Merchant* oil. Splits of significant samples from all cruises are being forwarded to the NOAA National Analytical Facility in Seattle, for complete GC-MS analysis under the direction of W. MacLeod. Petroleum concentration levels in these samples will also be determined by ultraviolet fluorescence and combined high pressure liquid chromatographic and fluorescence spectroscopic techniques by the USCG Research and Development Center and by Mississippi State University.

Analyses of sediment and water column samples collected on the *Endeavor* 003 and 004 cruises are still in progress. Preliminary analyses of stations occupied in the vicinity of the bow section of the *Argo Merchant* indicate high levels of *Argo Merchant* oil in the sediment. Analyses of three sediment samples collected at station G-43 on the *Endeavor* 004 cruise indicate concentrations higher than 50 parts per million based on wet sediment, with the highest level found in grab 2 at station G-43. Tables 3-4 and 3-5 summarize the preliminary sediment analysis data for samples collected in the vicinity of the bow section of the *Argo Merchant*. All concentrations are approximate levels of concentrations based on the December 19 sample collected by J. Mattson and J. Galt of NOAA. Analysis of water column samples collected on the *Endeavor* 004 cruise, incidentally, again indicate no presence of polyaromatic hydrocarbons.

3.2.4. Summary

If the *Argo Merchant* oil has entered the water column in any significant amounts, only the light aromatic fractions have done so. There is no evidence to date of any significant amounts of the heavy polyaromatics. Analyses are in progress to determine if there is a relationship between the

Table 3-4. Estimated oil concentrations per cubic centimeters of wet sediment samples collected on the *Endeavor* 004 cruise

Sample	Concentration (parts per million)	Sample	Concentration (parts per million)
G-43 Grab 1	> 50	D-35 Grab 1	<0.1
G-43 Grab 2	>100	D-35 Grab 2	<0.1
G-43 Grab 3	> 10	D-35 Grab 3	<0.1
D-36 Grab 1	>0.1	G-41 Grab 1	<0.1
D-36 Grab 2	<0.1	G-41 Grab 2	<0.1
D-36 Grab 3	>3.0	G-41 Grab 3	<0.1
G-42 Grab 1	>1.0	A-34 Grab 1	<0.1
G-42 Grab 2	<1.0	A-34 Grab 2	<0.1
G-42 Grab 3	>1.0	A-34 Grab 3	<0.1
A-40 Grab 1	<0.1	A-33 Grab 1	<0.1
A-40 Grab 2	<0.1	A-33 Grab 2	<0.1
A-40 Grab 3	>1.0	A-33 Grab 3	<0.1
C-39 Grab 1	<0.1	B-18 Grab 1	<0.1
C-39 Grab 2	<0.1	B-18 Grab 3	<0.1
C-39 Grab 3	<0.1	F-28 Grab 1	<0.1
C-23 Grab 1	<0.1	B-7 Grab 1	<0.1
C-23 Grab 2	<0.1	B-7 Grab 2	<0.1
B-15 Grab 2	>1.0		
B-15 Grab 3	<1.0		

light petroleum fraction found in the water column and the lighter components of the *Argo Merchant* oil. However, since representative samples of the original cargo of the tanker are not yet available, the December 19 slick sample collected by Mattson and Galt will be used in the interim.

Bottom photographs taken by the USCGC *Evergreen* indicate a clean bottom, which supports the sediment screening results for the samples collected on the *Evergreen*, and *Delaware II* 76-13 and 77-1 cruises.

Analyses of sediment samples collected in the area around the bow section of the *Argo Merchant* show considerable levels of oil from the tanker, and since these levels have been found only in this vicinity it is reasonable to infer that residual oil remaining in the bow section was imparted to the sediment as the bow drifted along the bottom toward deeper water. All sediment screening results to date are summarized in Tables 3-4 and 3-5, which indicate a moderate degree of PHC contamination throughout the area. An indication of *Argo Merchant* oil found in B-15 grabs 2 and 3 from *Endeavor* cruise 004 has been noted and is being investigated. The presence of *Argo Merchant* oil shown in Figure 3-6, can best be explained at present by the bottom transport of suspended oil sediments. Bottom currents in December and January in the area are 10 centimeters per second (Bumpus, 1973), which is sufficient to keep sand (grain sizes from 0.125 to 0.75 mm), the primary

Table 3-5. Preliminary thin-layer chromatographic screening of sediment samples

Sample	Concentration
Evergreen	
A-1	-
A-2	-
A-3	-
A-4	-
B-1	-
B-2	-
B-3	-
B-4	-
C-1	-
C-2	-
C-3	+
C-4	-
D-1	-
D-2	-
D-3	-
D-4	-
Oceanus 20	
1A	++
1B	+
1C	0
2A	+
2B	0
2C	+
3A	0
3B	+
3C	+
4A	+
4B	+
4C	+
5A	+
5B	++
5C	+
6A	+
Oceanus 20	
13A	+
13B	+
13C	+
14A	+
14B	+
14C	+
Oceanus 19	
1:1(A)	+
1:2(B)	+
1:3(C)	+
2:1(A)	+
2:2(B)	+
Delaware II 76-13	
4	0
6	0
Delaware II 77-01	
6	0
7	+
10	+
11	+
12	+
14	0
18	0
21	+
23	+
27	+
29	+
31	0
35	+
36	+
38	0
39	+

Table 3-5. Continued.

Sample	Concentration	Sample	Concentration
Endeavor 004		*Endeavor* 004	
A-31:1	+	D-36:1	+ +
A-31:2	0	D-36:2	- -
A-31:3	0	D-36:3	+
A-33:1	+	A-34:1	+
		A-34:2	+
G-43:1	+	A-34:3	0
G-43:2	++		
G-43:3	+	A-40:1	0
		A-40:2	-
G-42:1	+	A-40:3	+
G-42:2	+		
G-42:3	+	C-39:1	0
		C-39:2	+
G-41:1	+	C-39:3	-
G-41:2	+		
G-41:3	0		

- = no fluorescence.
0 = less than or equal to 2 micrograms per 5 cubic centimeters of wet sediment.
+ = more than 2 micrograms per 5 cubic centimeters of wet sediment.
++ = very high levels.

sediment type in the area, in suspension and move the suspended load at approximately 3 kilometers per day. Ths explanation is further substantiated by comparing the sediment screening results shown in Table 3-5 for *Evergreen* station B and *Endeavor* station G-42. The former based on samples taken in December, indicate a clean bottom; the latter, based on samples taken in February, indicate the presence of *Argo Merchant* oil. The conclusion arrived at is that the movement of the tanker's bow section, after it was sunk on December 31, over the sand bottom mechanically worked oil into the sediment and these sediments are being transported by the southwesterly bottom currents in the area.

References

Beerstecher, E., Jr., 1954. Petroleum Microbiology. Elsevier Press, Houston, Texas, 375 pp.

Betancourt, D. J., and A. Y. McLean, 1973. Changes in Chemical Composition and Physical Properties of a Heavy Residual Oil Weathering Under Natural Conditions. J. Inst. Petroleum, Vol. 59, pp. 223-230.

Forrester, W. D., 1971. Distribution of Suspended Oil Particles Following the Grounding of the Tanker *Arrow*. J. Marine Research, Vol. 29, pp. 151-170.

Johnson, F. H., W. T. Goodale, and J. Turkevich, 1942. J. Cellular Comp. Physiol., Vol. 19, pp. 163-172.

Stone, R. W., M. R. Feuska, and G. C. White, 1942. J. Bact., Vol. 44, pp. 169-178.

4. INVESTIGATIONS OF BIOLOGICAL PROCESSES AND EFFECTS

Most studies of the biological effects of oil have been done in laboratory or in nearshore areas. Extensive field studies that distinguish real effects from naturally occurring ecosystem variability are virtually nonexistent.

Although before-after studies can be designed to assess the impact of predictable events, such as oil drilling on the Continental Shelf and ocean dumping of wastes, adequate studies of this nature are lacking, because it is both difficult and expensive to plan and execute these investigations given the limitations of time and available funding.

The grounding and breaking of the *Argo Merchant* and subsequent groundings of other oil tankers on the Continental Shelf are dramatically illustrative of events that are not predictable. For example, during the past 18 months, the Northeast Fisheries Center has been requested by responsible officials--local, state and federal--to assess the impact of four major environmental incidents on the fishery resources of the northeast Continental Shelf. In each of these incidents, special studies were mounted to assess the impact on the environment and living resources. These efforts, however, were of limited duration, and little information on the baseline conditions or health of the stocks is available. We are dealing with a complex ecosystem that requires a combination of short-term tactical observations that can be evaluated against a background of long-term baseline information on the condition and health of fish and shellfish stocks.

In order to effectively deal with these problems a program is needed that (1) encompasses the coördination of studies of various groups and agencies, (2) provides for the fundamental and long-term study of the ocean ecosystem that is ultimately necessary, and (3) produces suitable information for interim or near-term policy guidance and decision making.

An integrated field approach is necessary, which couples in-depth "process oriented" studies at specific sites with long-term monitoring of productivity of fish stocks.

At present, no single program exists that can accommodate these objectives. However, NMFS, NOAA, is developing a plan to monitor and assess selected systems and biological and environmental parameters that are critical indicators of the state of health of the ocean. The plan calls for a long-term federal effort to acquire, process, analyze, and disseminate information concerning the condition, stability, and productivity of marine populations.

4.1 Fisheries Investigations

The impact of the *Argo Merchant* oil spill on the fish and shellfish stocks of Nantucket Shoals and southern Georges Bank is difficult to assess in the short term of 2 months. The National Marine Fisheries Services (NMFS) NOAA, has been conducting semiannual surveys of groundfish from the Gulf of

Maine to Cape Hatteras for the past 15 years to assess and predict changes in abundance of the principal fish stocks in the area. Major changes before the *Argo Merchant* spill have been the result of the interaction between intensive fishing and natural environmental fluctuations, which had reduced the fish biomass substantially from former abundance levels in the 1950's and early 1960's.

To date no comprehensive study has been carried out on the effects of oil on the productivity of fish populations on the northeast Continental Shelf. In fact, most studies concerning the effects of oil on fish and shellfish have been concerned with the onshore or nearshore impacts on littoral organisms. Definitive results on the effects on populations of fish are rare. Laboratory studies have shown that crude oil can damage embryos (Kühnhold 1969, 1974). Also, the zooplankton food of fish larvae have been found to suffer high mortalities from exposures to crude oil in laboratory experiments (Mirnov, 1969a, b). In contrast, recent observations from collections made at sea have indicated that zooplankton particularly copepods, can ingest particles of oil and pass them through the gut without any apparent effects. Some species of adult fish have been observed to avoid areas contaminated with oil. However, the more sensitive egg and larval stages are carried by the tides and currents and lack the ability to avoid oil spill areas. Bivalve shellfish (quahogs, scallops, mussels) are sedentary and have only limited capability to remove large amounts of petroleum hydrocarbons. They have been found to suffer significant mortalities in areas contaminated with oil (Jeffries and Johnson, 1975). Proper assessment of the impact of a major spill on the Continental Shelf requires the combined effort of extensive sea sampling and laboratory support studies. The following investigations are among the first attempts to determine how oil spilled on the Continental Shelf affects the productivity of fishery resources. Only by conducting integrated studies concerning physiological, genetic, and pathological effects on metabolism and reproduction through surveys of changes in the abundances of populations can we begin to define the real extent of damage caused by the oil.

On December 17, after meeting of scientists of Woods Hole had discussed plans for research in the event of the breakup of the *Argo Merchant*, the *Delaware II* was contacted and informed of the possibility that the ship might be diverted to the scene of the spill to conduct research. On December 20, the *Delaware II* terminated its trawl survey operations, steamed to Woods Hole, Massachusetts, and prepared for a short cruise to survey the fish stocks, ichthyoplankton, and benthic organisms around the oil spill. The ship arrived on December 21 and a group of NMFS scientists from Woods Hole and Narragansett, Rhode Island, under the direction of Henry Jensen, prepared to sail as soon as possible. The cruise plan was to sample near the edge of the oil slick without contaminating the sampling gear or the ship, and to obtain as many samples of water, fish, benthic organisms, and plankton as time would permit. The ship sailed on the afternoon of December 22, began fishing that night, and, after occupying 11 stations (Figure 4-1), returned to Sandy Hook on December 24.

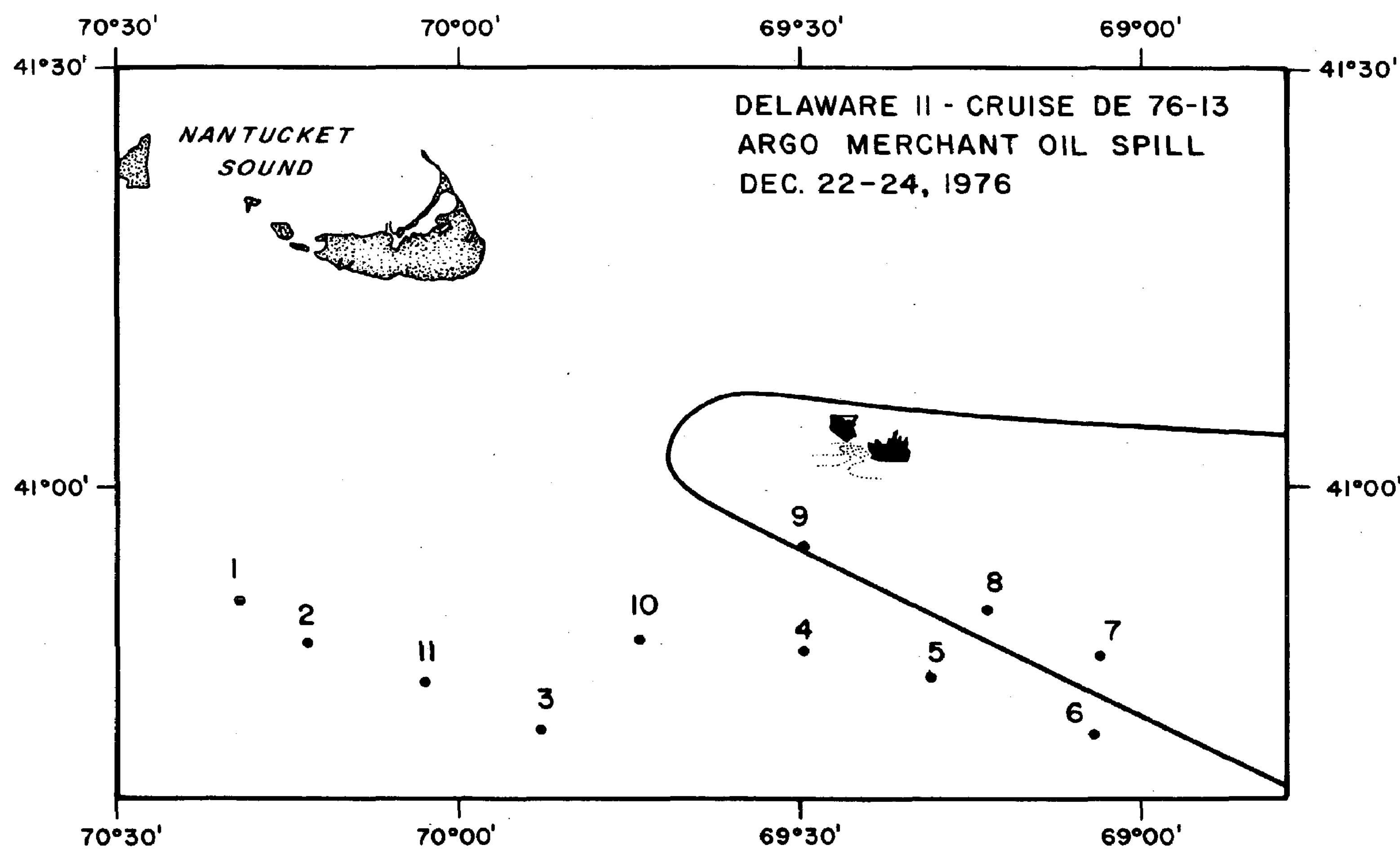


Figure 4-1. Station locations, *Delaware II* cruise DE76-13. Oiled area indicated by solid line.

Planning for the second cruise of the *Delaware II* was done more deliberately than for the first, but still in an atmosphere of emergency. The *Argo Merchant* had broken up and the oil had spread more than 150 miles to the east-southeast, crossing part of the South Channel and the southwest of Georges Bank. Maps of oil slick location observed from USCG overflights were used as a guide in the selection of sampling stations.

Since no one knew if the oil had mixed downward in the water column or had reached the bottom, it was impossible to define the contaminated area with any certainty. Three categories of stations were identified and selected for sampling: (1) control stations well away from the site of the spill and outside the influence of the spill overrun; (2) possibly contaminated stations outside the immediate area of the wreck, but under the overrun of the drifting oil spill; and (3) probably contaminated stations within about 20 miles of the wreck and under the overrun of the heaviest and most persistent concentrations of the drifting oil.

Approximately 65 sampling stations were designated, based on random selection of stations within each numbered series of depth strata normally used on NMFS groundfish trawl surveys. These stations were scattered through-out much of Georges Bank south of 41° 45'N latitude and east of 70° 00'W longitude. Several control stations were selected east of Cape Cod near Wellflett, and the plan was for the *Delaware II* to go out through the Cape Cod Canal and sample the control stations first. Initially, the ship would stay north of the potentially contaminated area, work eastward across Georges Bank in the uncontaminated area, then work south across the path of the slick overrun, and finally return westward into the area that held the greatest prospect of contamination.

This plan was followed on cruise DE 77-01 through the first 28 stations, when the cruise was disrupted by stormy weather and the ship sought shelter near Martha's Vineyard. She returned to the vicinity of the spill when the weather improved and successfully completed an additional 11 stations before being forced to return to Woods Hole by a severe storm. The locations of these stations are shown in Figure 4-2. A description of the observations and collections made on both cruises is given in Appendix V. Included in the *Delaware II* cruise reports is a description of the surface sediments by R. Wigley, NEFC, Woods Hole, Massachusetts, from samples collected during these cruises.

The University of Rhode Island conducted a cruise of the *Endeavor* from December 26-29, 1976, with Jim Quinn as chief scientist. Two stations were occupied, and the following biological samples were taken: (1) one bongo net tow with 0.505 and 0.333 millimeter mesh nets at each station at various depths; (2) plankton net tows on two occasions at each station to sample the water column at the surface and 10- and 20-meter depths; (3) grab samples for sediment and benthic organisms at each station using a Smith-McIntyre grab sampler (three at Station 1 and four at Station 2). Only one usable sediment sample was obtained at Station 2; the rest produced only small pebbles and shells, indicating the possibility of a gravel bottom.

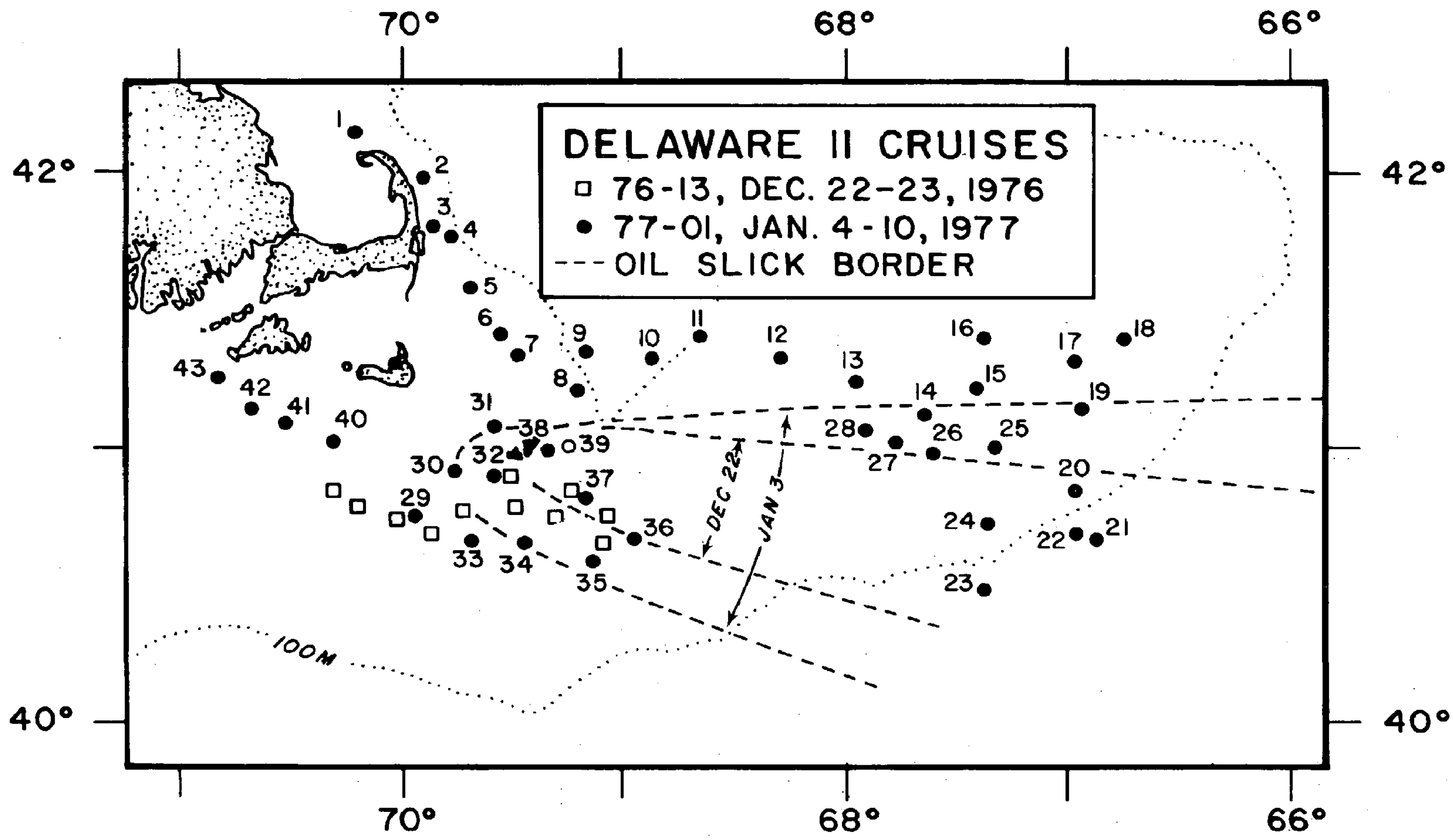


Figure 4-2. Station locations, *Delaware II* cruise DE77-01.
Oiled area indicated by dashed line.

Additional cruises of the *Endeavor* took place on January 26-29, February 8-12, and February 21-25, 1977. These cruises were designed to further delineate the amount of oil in the water column and in the sediments, as well as to continue the assessment of oil impact on the biology of the affected area. Reports on all four *Endeavor* cruises are contained in Appendix V.

The NMFS and URI are now beginning both an extensive sampling program and laboratory studies of fish, shellfish, and plankton populations that may have been damaged by the *Argo Merchant* spill. Twelve to 18 months will be required to complete the study and sort out the complex interactions among the levels of fishing mortality, natural mortality, oil mortality, and the sublethal effects of oil on the productive potential of fish resources. A short-term study based on the analysis of the results of three surveys of the spill area, laboratory observations, and an account of interviews with fishermen is underway. A brief summary of NMFS and URI studies is given below, including preliminary results.

4.1.1 Zooplankton Studies

The material in this section was contributed by R. Maurer of NMFS, NEFC, Narragansett, Rhode Island, and is based on samples collected during the first cruise of the *Delaware II* (DE 76-13).

A full array of plankton samples was taken at Stations 4 through 9 on the first *Delaware II* cruise (Figure 4-1 and Table 4-1). Standard oblique tows were made concurrently with large 61-centimeter bongos (0.505- and 0.333-millimeter mesh nets) and small 20-centimeter bongos (0.253- and 0.165-millimeter mesh nets), quantitatively integrating the water column from near the bottom to surface. In addition, 10-minute surface tows were made with a 1-by 1/2-meter neuston net (0.505-millimeter mesh net). Samples from the oblique tows (0.333-millimeter mesh net) were analyzed by the Plankton Sorting Center (NEFC, Narragansett) to provide information on plankton biomass, abundance, and diversity. Results from this analysis are presented in Table 4-2 and Table VII-15 in Appendix VII.

The dominant copepod species from each station were cleared (rendered transparent) with lactic acid and examined under a dissecting scope for the presence of oil. On the basis of a preliminary examination the contamination was classified as (1) external smudges on the exoskeleton; (2) mandibular particles adhering to feeding appendages or tar stains on mandibles (Figure 4-3); and (3) oil particles that had been ingested and were either stored or present in the gut, and/or incorporated in feces (Figure 4-4).

Zooplankton biomass ranged from 2.0 to 16.4 cc/100 m^3 (Table 4-1). The lowest biomass measured was within the oil slick area at Station 7, while the highest values were recorded at inshore Stations 4 and 9. Zooplankton numbers follow trends in biomass. Extremely high numbers and biomass occurred at Station 9, which was located on the boundary of the visible slick.

Zooplankton species abundance is shown in Table VII-15 in Appendix VII. Life stages indicate a separation of the more dominant forms into size categories of large, medium and small.

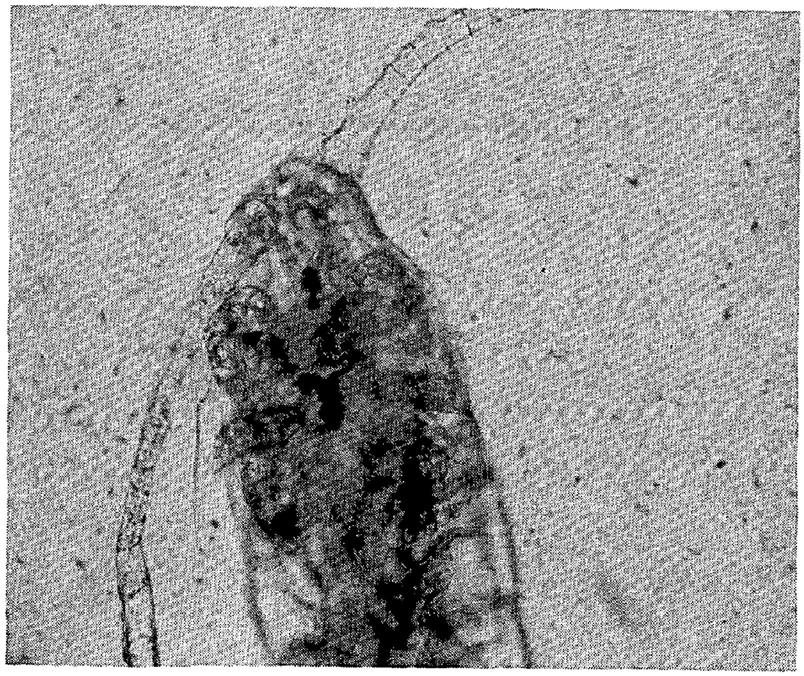
Table 4-1. Visual observations of oil and associated plankton biomass and numbers

Station No.	Observations	Displacement volume (cc/100 m^3)	Total zooplankton (numbers/100 m^3)
4	No oil noticed at surface; bongo samples clean; neuston with specks of tar.	12.1	51,358
5	No oil noticed at surface; bongo samples clean; neuston with specks of tar.	3.5	12,488
6	No oil noticed at surface; bongo samples clean; neuston with specks of tar.	4.2	2,259
7	Surface oil slick present; neuston nets fouled with oil.	2.0	2,352
8	Surface oil slick present; neuston nets fouled with oil.	6.8	28,240
9	Surface oil present in small amounts.	16.4	225,974

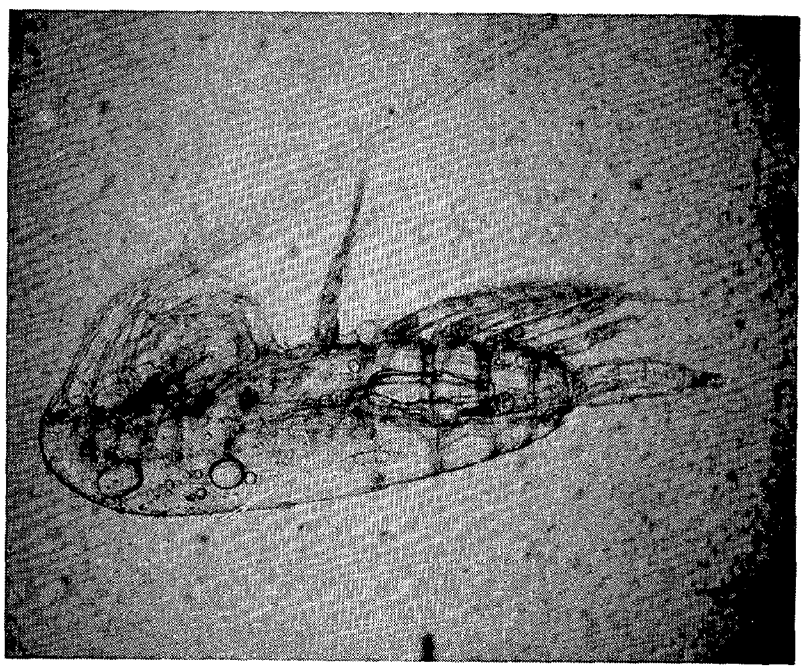
Table 4-2. Occurrence of oil contamination on dominant copepod species

Species	# Examined	# Contaminated	% Contaminated	Type of Contamination E	M	I
Station 4						
Centropages typicus	55	1	1.8	-	-	1
C. hamatus	10	2	20.0	-	-	2
Pseudo-Paracalanus	163	8	4.9	5	-	5
Station 5						
Calanus finmarchicus	20	11	55.0	2	3	6
Centropages typicus	100	61	61.0	1	1	59
Pseudo-Paracalanus	100	25	25.0	-	18	7
Station 6						
Calanus finmarchicus	41	1	2.4	-	1	-
Centropages typicus	100	16	16.0	-	2	14
Pseudo-Paracalanus	21	0	0.0	-	-	-
Station 7						
Calanus finmarchicus	100	14	14.0	2	7	0
Centropages typicus	104	30	28.8	0	1	29
Pseudo-paracalanus	105	35	34.3	2	11	10
Station 8						
Calanus finmarchicus	76	12	15.8	-	10	2
Pseudo-Paracalanus	50	5	10.0	-	4	-
Metridia lucens	32	3	9.4	-	1	2
Station 9						
Centropages typicus	45	13	28.8	2	9	6
C. hamatus	8	3	37.5	1	2	-
Pseudo-Paracalanus	60	3	5.0	1	1	1

Types of contamination E = external
M = mandibular
I = ingested

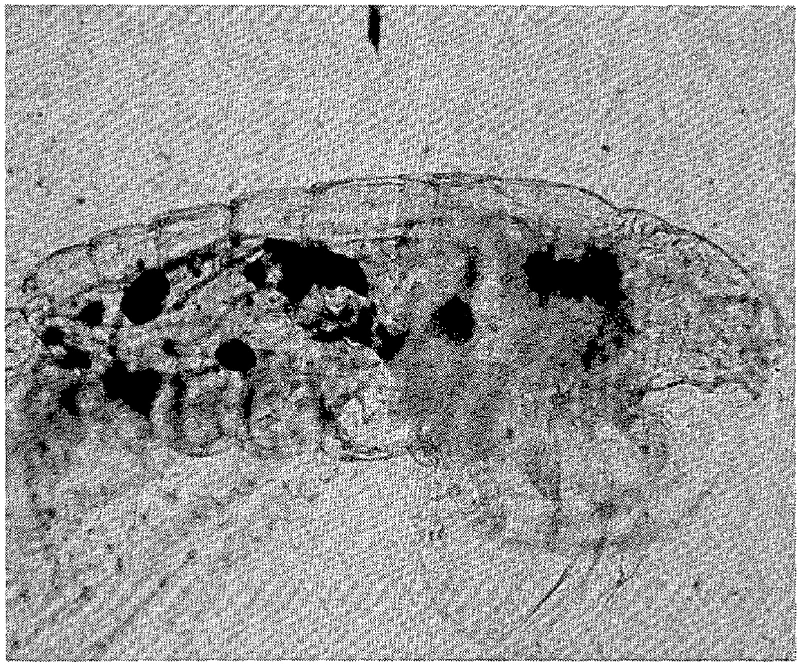


Centropages typicus, ventral view.

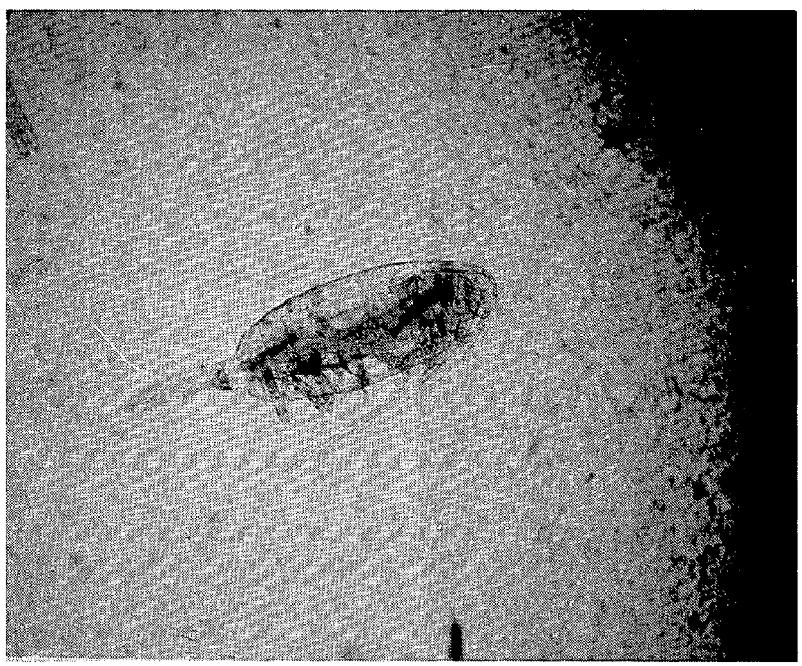


Calanus finmarchicus, lateral view.

Figure 4-3. Mandibular contamination. Oil particles adhering to feeding appendages. (Photographs by R. Maurer, NMFS, NEFC, Narragansett, Rhode Island.)



Centropages typicus; note rounded stored particles.



Pseudocalanus minutus; oil present only in alimentary tract.

Figure 4-4. Ingested contamination. Oil present in gut and natural oil storage areas. (Photographs by R. Maurer, NMFS, NEFC, Narragansett, Rhode Island.)

Considerable differences in biomass, total numbers, and species composition, as well as individual species abundance occurred within relatively short distances (10 to 25 miles) from Nantucket Shoals to Great South Channel, as shown in Tables 4-1 and VII-15 (Appendix VII). These differences can be used to define the communities and to pair the stations as follows:

1. Stations 4 and 9 - Shoal Community - Nantucket Shoals. These stations are characterized by a shallow (40 meters), well-mixed physical environment, extremely turbulent during winter months. Zooplankton numbers are strongly dominated by small calanoid copepods of the genera *Pseudocalanus* and *Paracalanus*, with medium-size developmental stages, comprising 73% (Station 4) and 50% (Station 9) of their numbers. These have been lumped together and will be referred to as *Pseudo-paracalanus*. The turbulent nature of this shoal environment is demonstrated by the large number of gammarid amphipods, especially *Monoculodes*, in the collections. These specimens were apparently lifted into the water column in the vertical turbulence.

The incidence of contamination at Station 4 (Table 4-2) was quite low for *Centropages typicus* and *Pseudo-paracalanus*. A somewhat higher value was recorded for *C. hamatus*, of which only 10 specimens were examined. *C. typicus* samples along the slick boundary (Station 9) were found to have a relatively high incidence of mandibular and ingested particles.

2. Stations 5 and 8 - Transitional Community. These stations, taken at about 55 meters, exhibit characteristics of both the shoal and channel communities. Numbers again are dominated by *Pseudo-paracalanus*, especially at Station 8. A larger calanoid, *Centropages typicus*, appears as a codominant form. Total zooplankton numbers are 5 to 10 times less than those recorded at the adjacent shoal stations. Contamination appears greatest at Station 5, outside the slick. Over 50% of the *C. finmarchicus* and *C. typicus* were affected; most contained ingested particles.

3. Stations 6 and 7 - Channel Community. This is a distinctly different community, characterized by low biomass, low total numbers, and dominated by larger copepods, *C. finmarchicus* (Station 7), and *C. typicus* (Station 6). This assemblage is similar in part to the "*Calanus* community" of the Gulf of Maine (including *Calanus finmarchicus*, *Pseudocalanus minutus*, *Metridia lucens*, *Sagitta elegans*, and *Parathemisto*) and unlike the Georges Bank winter community, which Clarke et al. (1943) showed to be *Pseudocalanus* dominated. Contamination at Station 6 outside the slick is low, while inside the slick at Station 7 a high number of ingested particles were recorded for *C. typicus* and *Pseudo-paracalanus*.

Significant contamination was found in copepods in all three communities, and the occurrence was not restricted to the visible slick area (Table 4-2), indicating that oil contamination occurred in a major component of the food web. Oil droplets removed from the alimentary tracts of the predominant copepod species, *Centropages typicus*, were examined for petroleum hydrocarbon content using gas chromatography. The resulting chromotagrams were compared by W. W. Kühnhold (University of Kiel, FRG) and R. Lapan (EPA) with chromatograms of oil from the *Argo Merchant* and were found to be similar.

When oil is incorporated into the feces of zooplankton the specific gravity of the combined pellet (oil and feces) is greater than the oil before ingestion, and it therefore sinks in the water column (Parker et al., 1970). Ingestion by plankton animals acts as a precipitation mechanism for otherwise buoyant oil particles. The contaminated fecal pellets may then either become covered by sediment or ingested by detritus feeders.

The impact of oil on zooplankton is not clear. The observed oil contamination could affect feeding and reproduction. Sensitive chemoreceptive pores are located along the dorsal exoskeleton of copepods. The pores are used for positioning during reproduction. If they were to become impacted with oil, the individual probably would not be able to reproduce successfully.

Mandibular contamination shown in copepods in Figure 4-3 may interfere with the handling and ingesting of desired food particles. The toxicity of ingested oil is poorly understood. The degree of toxicity depends on the presence of volatile, aromatic compounds that are released through time as the oil "ages." Additional studies are planned by NMFS to assess the effects of petroleum hydrocarbons on zooplankton.

4.1.2 Ichthyoplankton Studies

Ichthyoplankton studies were contributed by W. Smith, D. Busch, L. Sullivan, and K. Sherman of NEFC laboratories at Sandy Hook and Narragansett and are based on samples collected during the first cruise of the *Delaware II* (DE 76-13). Fish eggs and larvae were collected with paired bongo samplers and a surface neuston net at Stations 4 through 9 on the first *Delaware II* cruise (DE 76-13) using standard Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) sampling procedures (Figure 4-1). Stations 7 and 8 were within the area of oil pancakes. Station 9 was at the boundary between "clean" and oil-contaminated surface water, while Stations 4, 5, and 6 were outside the southern periphery of the oiled area. The neuston nets towed on Stations 7 and 8 were saturated with oil (Figure 4-5).

Only two species of eggs were in the samples: cod and pollock. Pollock eggs were most numerous within and adjacent to the spill zone, at Stations 7, 8, and 9, while cod eggs were concentrated around the periphery of the spill, at Stations 4, 5, and 6 (Figure 4-6).

At Station 9 adjacent to the spill area, oil globules were found adhering to the surface membrance (chorion) of 93% of the pollock eggs. Of these eggs, later examined by A. Longwell at the NMFS Milford Laboratory, 98% were dead or moribund as determined through cytogenetic examination. In contrast, only 64% of the cod eggs showed evidence of oil contamination. At Stations 4, 5, and 6 outside the spill area, more of the eggs were viable.

Six species of fish larvae were in the collections: sand launce, cod, pollock, rockling, hake, and herring. Of these species, only sand launce was abundant. Other larvae were rare (Table VII-16 in Appendix VII). The abundancede of sand launce decreased sharply at the two sampling stations within

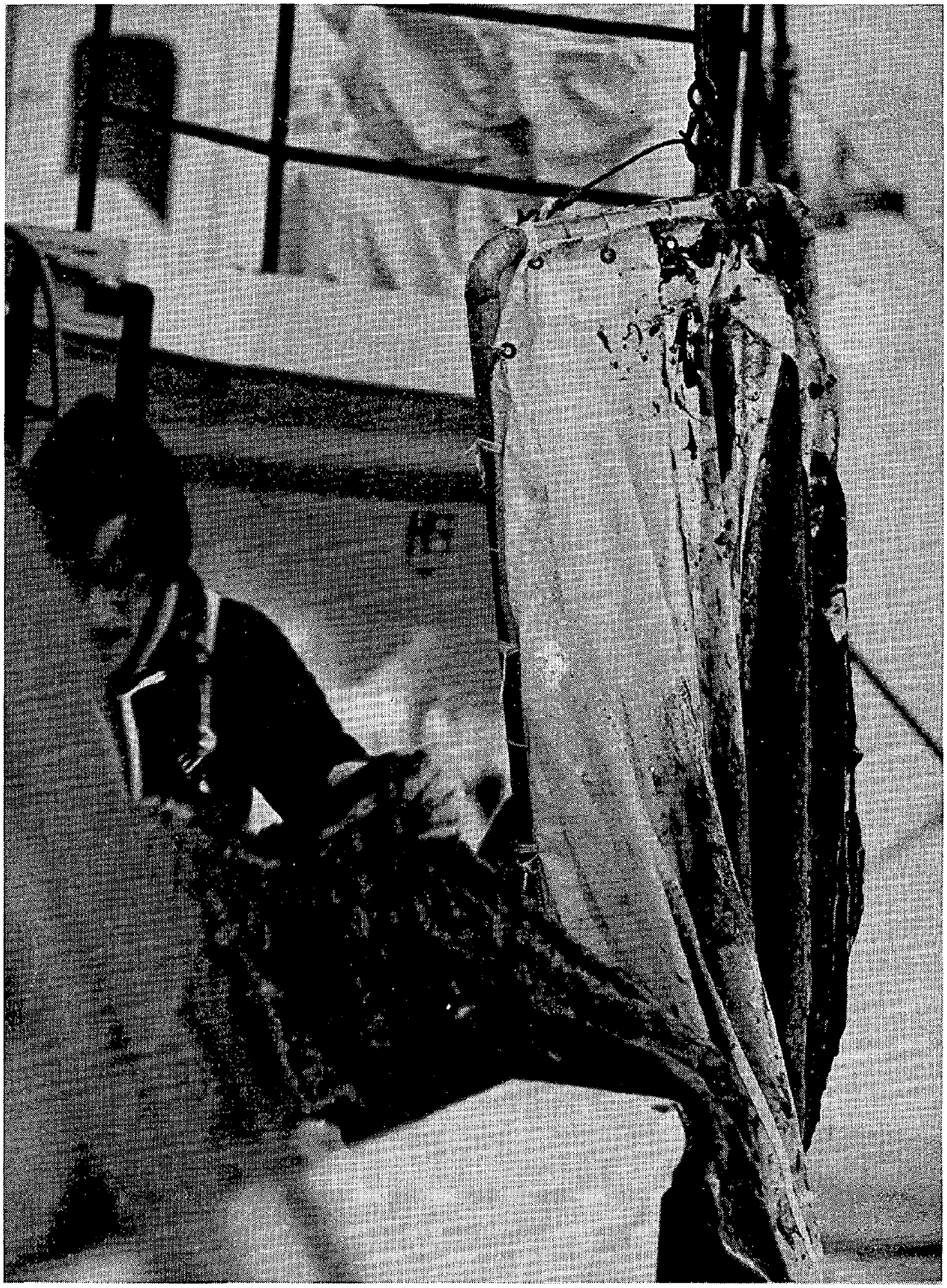


Figure 4-5. G. Carter, NMFS, holds oil-saturated neuston net after station 8 on *Delaware II* cruise DE76-13. (Photograph by R. Bolsvert, NMFS.)

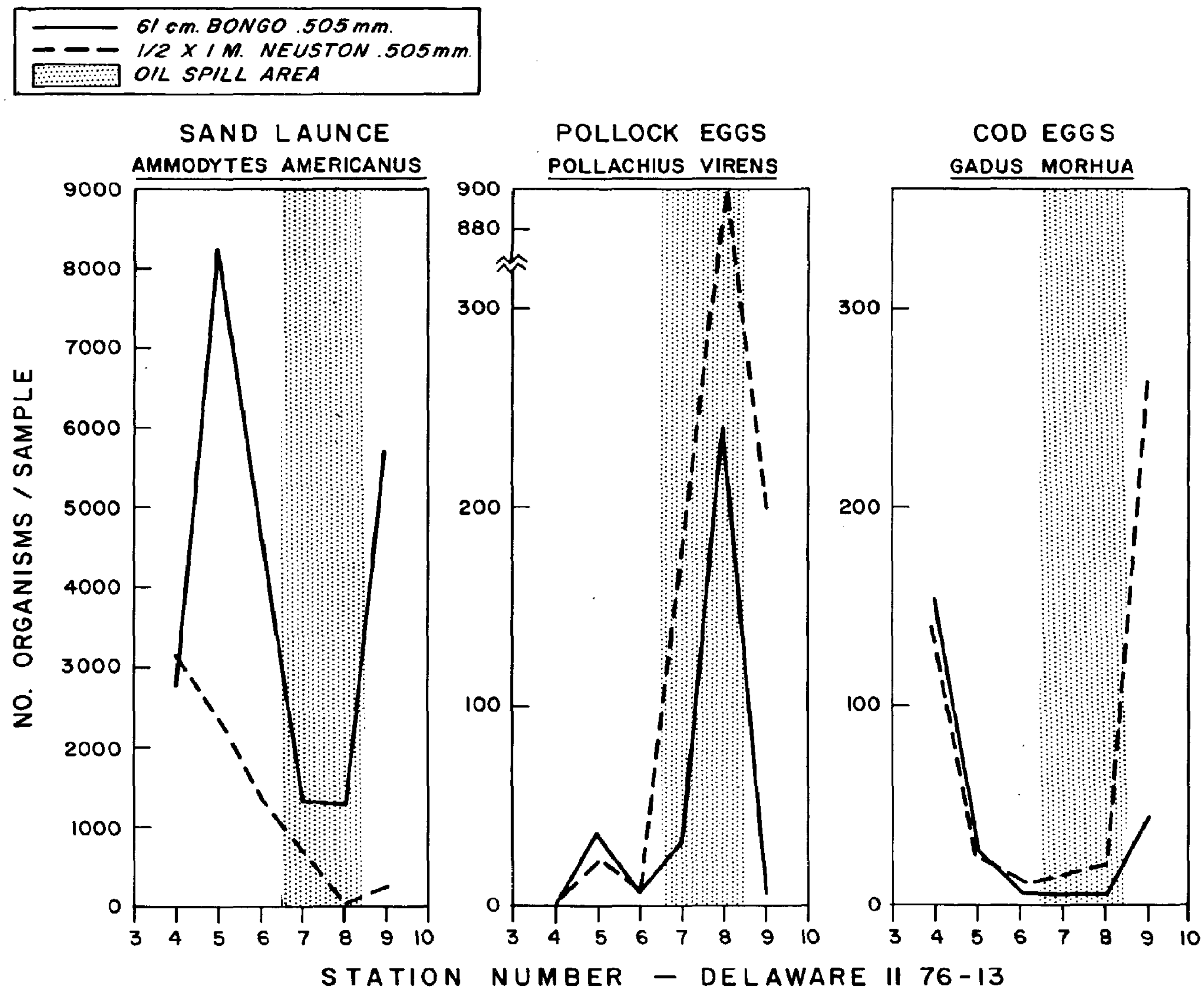


Figure 4-6. Numbers of fish larvae and eggs collected on *Delaware II* cruise DE76-13.

the spill area. The reasons for the decrease are not clear, but the analysts assume that the decrease in population may be associated with the negative impact of the oil on the viability of larvae. Samples collected from this area during the second *Delaware II* cruise, DE 77-1, will be examined to corroborate this assumption. The sand launce, while not important in the commerical fishery, is a key species in the ecosystem. It is the basic food of predatory fish, including cod, haddock, silver hake, as well as marine mammals, including porpoises and whales. Little can be said about the other species as they occurred in very low numbers (15 per station) over the entire survey area.

The most notable change was in the decrease of sand launce larvae at Stations 7 and 8 within the spill zone. This decline in abundance may have been related to *Argo Merchant* oil contamination. Additional sampling of the area will be conducted to assess sand launce stocks in an effort to estimate the range of "normal" variation in population distribution and abundance. Also, mortality among pollock eggs was increased significantly in the area of the spill, as evidence by the large numbers of moribund embryos in eggs contaminated with oil. Cod mortality occurred but was lower. Studies are underway to obtain estimates of the extent of mortality inflicted on the populations of both cod and pollock stocks by the *Argo Merchant* oil.

4.1.3 Genetic Studies

These studies were contributed by A. Longwell of NMFS, NEFC, Milford, Connecticut and are based on samples collected on the first cruise of the *Delaware II*, DE 76-13.

It has been demonstrated in the laboratory that compounds extracted from oil films are toxic to fish larvae and to the early developmental stages of planktonic fish eggs. Failure in the past to establish detrimental effects of oil spills in the field may be attributable to the lack of sufficient, appropriate field tests that might be conducted quickly and cheaply enough when the need arises, as well as to the fortunate resiliency of the ecosystem. However, extrapolation of laboratory data to the field without adequate field testing can be done only with the utmost caution.

Toxicity of oil components will, of course, vary according to the developmental stages of the eggs at exposure. That there are sublethal effects which lead to later mortality of the fish eggs is evident from the published literature on experimental studies. Teratogenic effects (deformities) are common in oil toxicity tests.

Aromatic hydrocarbons are highly soluble in lipid material as present in the yolky contents of fish eggs. Polynuclear aromatic hydrocarbons can act both as carcinogens and mutagens. Benzene, the most abundant aromatic compound in crude oil, has been proved mutagenic in a number of published genetic tests on organisms other than fish. Concentration of such hydrocarbons in the fatty material of spawned eggs may, accordingly, well provoke both cytotoxicity and mutagenicity to the chromosome apparatus in the critical early development stages of planktonic or demersal fish eggs. Their absorption through the membrances of planktonic fish eggs spawned in the vicinity of oil spills could similarly provoke these effects, which would almost invariably be lethal to the egg. Cytotoxicity, mutagenicity, and less direct physiological effects on the chromosomes and nuclei of the early-stage eggs ought to depress the rate of their cell and chromosome divisions.

In light of these findings and in response to the oil spill, an effort was undertaken to determine the cytogenetic effects of oil on fish eggs.

Microscopic examinations were made of the dissected embryos of 79 cod eggs and 153 pollock eggs sampled in the vicinity of the *Argo Merchant* oil spill. This was done using a new application of cytogenetic methodology to fixed fish eggs from field plankton samples (Longwell, 1976). Similarly examined were 75 cod embryos from eggs spawned in an aquarium by a small number of females captured in the field.

Sample size and station numbers are drastically limiting, and pollock eggs were not represented in the sub-sample from Station 4. Even so, a higher mortality of pollock over cod eggs is obvious. Totaled over all stations, about 20% of the collected cod eggs were dead or cytologically moribund as compared with 46% of the pollock eggs. For comparison, only 4% of the sample of cod eggs spawned in the laboratory were dead or moribund (Table 4-3). The earlier developmental stages of the cod eggs studied should have been more sensitive than the pollock eggs because natural mortality rates are highest in younger embryos. Thus, any real difference between the viability of cod and pollock eggs may be even greater than the numbers alone indicate.

At Station 8 the pollock embryos were malformed in 18% of the eggs; at Station 9, in 9% of the eggs. Pollock eggs at Station 9 carry the strongest implications for an adverse effect of the oil. Here mortality and moribundity was 98% for a reasonable sample size (43 eggs). About 60% of these eggs had strikingly abnormal cell patterns. The large size of the cells of these embryos can be interpreted as indicating that the influencing factor acted much earlier in embryo development than the tail-bud and tail-free stages at which the abnormal pattern was observed. In these embryos, chromosome and cell division had almost entirely ceased or was blocked at the prometaphase division of mitosis (a common action of chemical adversely affecting the chromosome apparatus). Almost all the rest of the pollock embryos at this station were merely degenerating examples of this type of abnormal embryo (Table 4-4).

Oil adhered to almost all the pollock eggs from Station 9 (Figure 4-7), and the amount of oil on individual eggs was also greater than at the other stations. At this same station, fewer cod eggs were contaminated and the individual eggs were not as heavily contaminated as the pollock eggs. The reasons for the differential contamination are unclear. The pollock eggs were at a later developmental stage than the cod eggs and may have been sampled higher in the water column than the earlier stage cod, thus increasing their chance of being contaminated with oil particles. The fixation of the eggs may affect the adherence of oil to the egg membranes. The membrane contamination observed in the fixed eggs is certainly real, however, suggesting the possibility of species differences in membrance fouling. Normal

Table 4-3. Cytological assays of mortality and moribundity of cod and pollock eggs from the vicinity of the oil spill

	Total No. eggs	No. eggs viable	No. eggs dead or moribund	% eggs dead or moribund	% eggs malformed
Station 4					
Cod	14	13	1	7.14	-
Pollock	-	-	-	-	-
Station 5					
Cod	6	3	3	50.00	-
Pollock	11	0	11	100	-
Station 6					
Cod	3	3	0	0	-
Pollock	3	0	3	100	-
Station 8					
Cod	1	1	0	0	-
Pollock	105	86	19	17.92	17.92
Station 9					
Cod	55	43	12	21.82	-
Pollock	43	1	42	97.67	9.30
Laboratory Spawning Cod	75	72	3	4.00	-

Table 4-4. Number of mitotic telophases of all cell division in pollock embryos at Stations 8 and 9

	Telophases (actual number or estimate)					
Pollock eggs	0	3-14	15-25	±50	±75	-100-+200
Station 8	6	7	8	27	8	28
Station 9	35	6	0	0	0	0

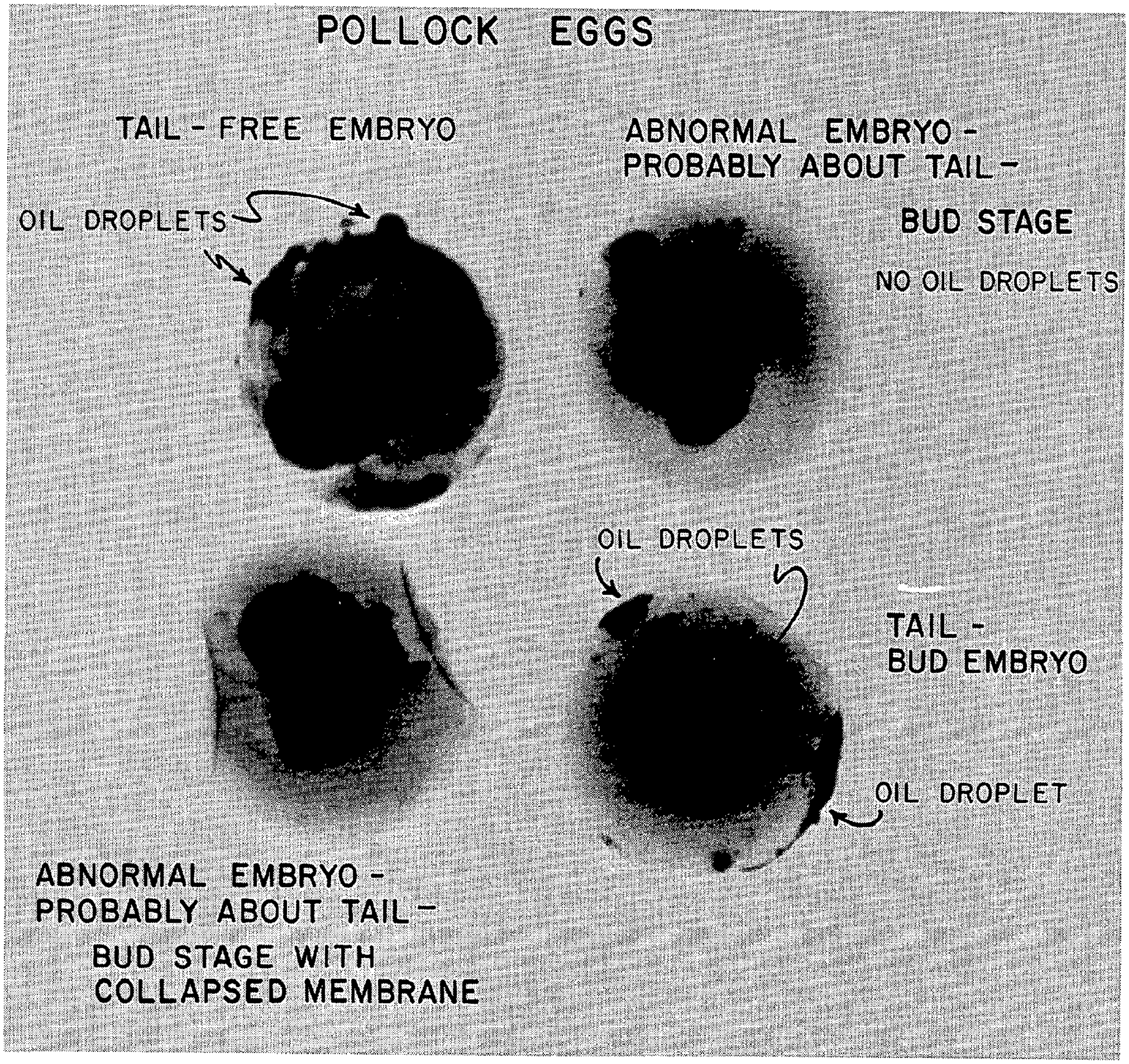


Figure 4-7. Oil droplets adhering to pollock eggs and abnormal pollock embryos collected in the area of the oil spill. (Photograph by D. Perry, NEFC, Woods Hole, Massachusetts.)

levels of mortalities during egg production in the natural environment are high. It is difficult to assess the effect of additional mortalities caused by oil on the cod and pollock in the area of the spill. More observations will be required to properly evaluate the population impact.

4.1.4 Effects of Oil on Developing Embryos

This section was contributed by W. Kühnhold, the visiting expert from the University of Kiel, FRG, at NMFS, NEFC, Narragansett, Rhode Island. Samples collected on the first cruise of the *Delaware II* DE 76-13 were used in these studies.

Laboratory experiments on the effects of No. 6 fuel oil on pelagic eggs W. Kühnhold and P. Lefcourt. These experiments deal with the direct effects of an oil film on floating eggs and also with the effects of the water soluble fraction of No. 6 oil on developing embryos.

At Station 9, which was located at the periphery of the oil-contaminated area, it appeared that oil was adhering in significantly greater quantities to pollock eggs than to cod eggs in neuston samples. To determine whether there were differences in surface membrance characteristics of the eggs that could result in differential adherence to the oil, experiments involving the exposure of pelagic eggs to an oil film were initiated jointly at the Northeast Fisheries Center's Narragansett Laboratory and the EPA Laboratory, Narragansett, by E. Jackim and R. Pruell. In these experiments, cod eggs were kept floating under an oil film, which was then stirred both gently and vigorously to mix the eggs with the oil. In no case was there any sign of oil adhering to the living eggs. The same results have been reported for cod eggs by James (1925) and by Kühnhold (1972) in tests with crude oil of a similar visocisty. So far, only cod eggs have been available for this test. The NMFS Narragansett Laboratory plans to expand this study to include pelagic eggs of several species, especially pollock, in order to determine whether there are differences in surface responses of fish egg membranes to oil among important fish species.

The experiments to determine the effect of the water-soluble fraction (WSF) of No. 6 oil conducted in cooperation with D. Everich of EPA have not been completed, and only preliminary results are available. These experiments are carried out as static tests to approximate conditions of an acute spill situation where a body of water may be covered with an oil slick for a short time only. The dissolved compounds are then subject to evaporation. The extraction of No. 6 fuel oil was prepared according to Hyland (1973) to provide concentrations of WSF comparable to earlier studies. Since no data were available about actual concentrations of WSF of the *Argo Merchant* oil at the spill site, initial concentrations of 500, 100, and 10 parts per billion (ppb) of total extractable hydrocarbons, WSF, were used. The loss of hydrocarbons during the course of the tests appears to be low, less than 50% in 10 days. Cod eggs were exposed at three different embryonic stages: 4 to 6 hours (2-cell stage), and 3- and 7-day old embryos.

High mortality was evident in the youngest embryo group at the highest concentration (500 ppb) after 24 hours. It was observed that the eggs held at 500 ppb sink to the bottom of the test jars prior to dying. This phenomenon is due to loss of osmoregulation in the embryonic organism. Some eggs may actually sink to the bottom several days before dying. It was also observed that the development was greatly delayed in the higher concentrations, and that the heart beat was greatly reduced. From the beginning of regular heart muscle contractions to hatching, the frequency normally increased from about 30 to 70 beats per minute in untreated eggs, while the treated eggs showed a decrease in frequency of heart beat to less than 20 beats per minute with very irregular muscle contractions. Anderson et al. (1976) have indicated that the heart beat rate can also serve as a sensitive indicator for sublethal effects. This was evident in the eggs exposed to the intermediate concentration (100 ppb), which in some cases showed no sign of developmental delay or abnormalities, but did have reduced heart beats. Ten ppb does not appear to increase embryo mortality or alter hatching rates.

Further evaluation of the data should clarify the relationship between hatching and survival rates of larvae and embryonic heart beat frequency.

4.1.5 Food Habits

This section was contributed by R. Langton and R. Bowman of NMFS, NEFC, Woods Hole, Massachusetts, and is based on samples collected from both *Delaware II* cruises (DE 76-13 and DE 77-01).

Stomachs were collected from fish caught with an otter trawl during the *Delaware II* cruises 76-13 and 77-01 (Figure 4-8; Table 4-5 and Table VII-17 in Appendix VII). The fish stomachs were excised aboard the ship, labeled according to species, length, and station, and preserved in 10% formalin. A total of 305 stomachs were collected from the 16 different species of fish.

At the NEFC laboratory, Woods Hole, the preserved stomachs were opened and the contents washed onto a 0.25-millimeter mesh screen. The various food organisms were manually sorted, identified to the lowest taxa possible (with a dissecting microscope when necessary), and damp-dried on bibulous paper. Each taxonomically distinct group was weighed to the nearest 0.01 gram on a Mettler balance immediately after being dried. Parasites in the stomach were included as part of the stomach contents. Food items of little dietary significance or those that were unidentifiable because of the degree of digestion were classified as miscellaneous.

For the purpose of analysis all information was pooled by species, regardless of size, for comparison with existing food habits data. Data for each predator are presented as a percentage of the total stomach contents weight and as mean weight per stomach. The mean weight per stomach was calculated by dividing the total stomach contents weight by the total number of stomachs examined.

The food habits of six species of fish were investigated following the first *Delaware II* cruise, DE 76-13, and are summarized in Table VII-18 in Appendix VII. The same six species plus an additional 10 were sampled during the second *Delaware II* cruise, DE 77-01 (Table VII-19 in Appendix VII). The food habits of the six co-occurring species were generally similar between

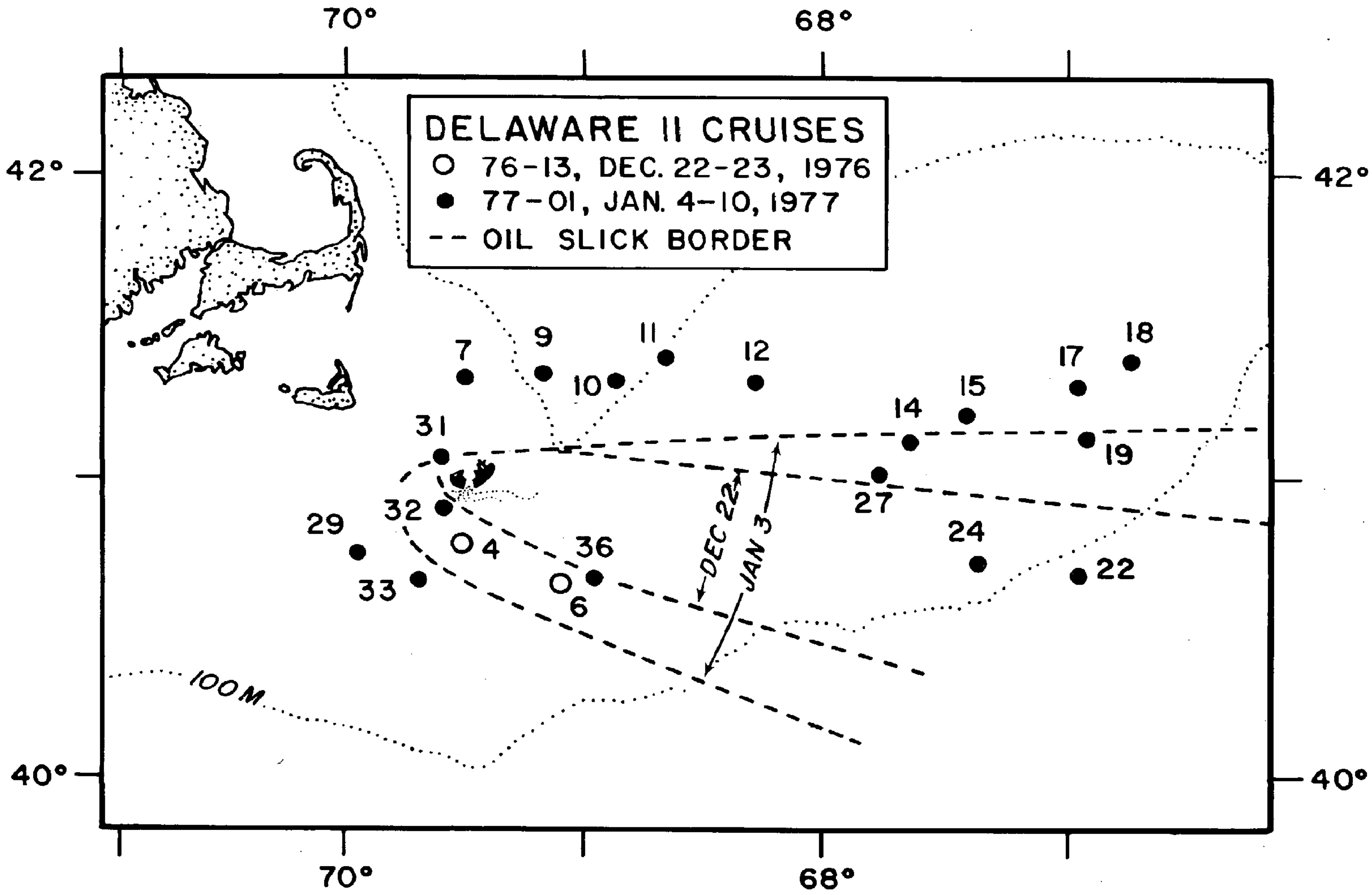


Figure 4-8. Stations where fish were collected for analyses of food habits.

Table 4-5. Stations and number of fish sampled for stomach content analysis on *Delaware II* cruises DE76-13 and DE77-01

Fish species sampled	Cruise: DEL II 76-13, Station 4	6	DEL II 77-01, Station 7	9	10	11	12	14	15	17	18	19	22	24	27	29	31	32	33	36	Species totals
Spiny dogfish		9											10								19
Little skate	40						11	6												6	63
Winter skate	7																			2	9
Thorny skate						4															4
Alewife																				10	10
Red hake														6							6
Haddock				5					6						10						21
Pollock				2		4											4				10
Atlantic cod	26			5				3		1					2	20				8	65
Ocean pout		4									2	2				5			6		19
Windowpane	5						13								15						33
American plaice					5																5
Blackback			3															2			5
Yellowtail			7						3										9		19
Sea raven											5										5
Longhorn sculpin						12															12
																				Grand total	305

cruises. However, it is difficult to evaluate any differences observed because of the relatively small number of fish collected. For example, the winter skate collected on the first cruise (76-13) consumed a greater percentage of fish (50.3% vs 12.9%), while more polychaetes (60.7% vs. 21.8%) had been eaten by the fish collected during the second cruise. The sample size was small, two and seven fish for the first and second cruise respectively, and therefore these differences may only reflect sampling variance. The small sample size also makes it difficult to accurately assess the differences in food habits between the windowpane and the ocean pout for the two cruises. The Atlantic cod also differed in its food habits, but in this case the sampling size was larger: 26 for cruise 76-13 and 39 for cruise 77-01. The cod collected during cruise 76-13 ate more crustacea (62.0% vs. 38.7%), while the amount of fish in the diet decreased (26.5% vs. 53.3%). The most striking difference was in the quantity of food consumed. The mean weight per stomach was 3.90 grams for the 76-13 cruise and 19.37 grams for the 77-01 cruise. The length range of the fish sampled on both cruises overlapped (35 to 86 centimeters vs. 33 to 100 centimeters), but the average length of the fish was slightly larger (44 vs. 57 centimeters) for the 77-01 cruise. Little skate were also sampled in relatively large numbers during both cruises (Tables 4-5 and Table VII-17 in Appendix VII). Again there were some differences in the food habits, but in both cases the major food items were crustaceans (84.2% and 48.1%). The mean weight per stomach was also similar, although there was a difference in the length range of the fish examined (Tables VII-18 and VII-19 in Appendix VII).

In the discussion that follows the stomach samples of each predator species are considered based on data from both cruises. The major dietary components of each fish within a designated category, determined phyletically, are described.

The first group, the Chondrichthyes, is comprised of the spiny dogfish, Squalus acanthias; winter skate, Raja ocellata; thorny skate, Raja radiata; and little skate, Raja erinacea. Over 95% of the diet of the dogfish was fish. The major prey items of the winter skate were polychaete worms (21.8% and 60.7%) and the sand launce, Ammodytes americanus (50.3% and 3.0%). The stomach contents of the thorny skate were composed of a high percentage of fish (43.4%) and polychaete worms (29.5%). The little skate primarily consumed crustaceans (84.2% and 48.1%), in particular gammarid amphipods (63.8% and 28.0%). In one sample from cruise 77-01, Station 36, consisting of the stomach contents from three male little skate ranging in length from 45 to 49 centimeters, an oil-like material was found on one caprellid amphipod.

The gadids included red hake, Urophycis chuss; haddock, Melanogrammus aeglefinus; pollock, Pollachius virens; ocean pout, Macrozoarces americanus; and Atlantic cod, Gadus morhua. The red hake diet consisted primarily of mud crabs (Axius serratus) and rock crabs (Cancer), which made up over 50% of the crustaceans (81.1%) eaten. Haddock consumed polychaete worms (24.2%) and ceriantharian anemones (59.5%). The major component of the stomach contents of the pollock was the sand launce, Ammodytes americanus (69.8%), while the prey of the ocean pout was primarily sand dollars, Echinarachnius parma (47.7%). The cod preyed on a variety of Crustacea (62.0% and 38.7%), rock crabs, Cancer irroratus and C. borealis; caridean shrimp, Crangon septemspinosa and Dichelopandalus leptocerus; the hermit crab, Pagurus acadianus; gammarid amphipod, Gammarus annulatus; and the isopod, Cirolina polita. The sand launce, A. americanus was the major species of fish identified in the cod stomachs (25.7% and 20.8%). In two samples from cruise 77-01, Station 29, an oily material was found mixed in with the stomach contents. In the first sample of nine fish, ranging in length from 41 to 45 centimeters, the oily substance was found in one stomach of the gammarid amphipod, Gammarus annulatus. In the second sample of six fish, ranging in length from 49 to 87 centimeters, the oily material was found on the gammarid amphipod, Anonyx sarsi.

The stomach contents of four species of Pleuronectiformes (flatfish) were examined: the American plaice, Hippoglossoides platessoides; winter flounder, Pseudopleuronectes americanus; windowpane, Scophthalmus aquosus; and yellowtail, Limanda ferruginea. Over 90% of the diet of the American plaice consisted of polychaete worms of the family Aphroditidae. The five winter flounder stomachs examined were empty. The windowpane was collected on both cruises and in each case crustaceans were the major prey item, being either primarily gammarid amphipod (90.2%) on cruise 76-13 or the caridean shrimp, Crangon septemspinosa (41.6%) on cruise 77-01. The stomach contents of the yellowtail were also comprised of a high percentage of Crustacea with the major prey item being C. septemspinosa (60.8%). Alewives, Alosa pseudoharengus, the only clupeid examined, fed almost exclusively on gammarid amphipods (96.4%) of the genus Gammarus.

The last group of fish examined were the cottids: the sea raven, Hemitripterus americanus, and the longhorn sculpin, Myoxocephalus octodecemspinosus. The sea raven ate fish almost exclusively (99.3%). Over 98% of the stomach contents of the longhorn sculpin were decapod crustaceans, with the major prey item being the pandalid shrimp, Dichelopandalus leptocherus (65.6%).

The food habits of the 16 fish examined in this survey differ little from data previously collected on the food habits of the same species (Maurer and Bowman, 1975; Bowman, 1975; Bowman et al., 1976). Only the data collected on the American plaice and haddock appear to differ in terms of the major prey item categories.

The stomach contents of the American plaice consisted almost exclusively of polychaete worms. However, only five fish were examined, of which three had empty stomachs and one of the two remaining had eaten polychaetes. In a larger sample of fish from southern New England and Georges Bank, Bowman et al. (1976) have shown that the major food items are usually crustaceans or echinoderms. Annelids are also a smaller part of the diet of these fish, especially in southern New England, and it is likely that a larger sample would have reduced the apparent significance of polychaetes in the diet of American plaice.

In the Georges Bank area haddock have generally been found to eat crustaceans, molluscs, echinoderms, annelids, and fish (Wigley, 1956; Wigley and Theroux, 1965). The occurrence of large quantities of coelenterates in the diet, as reported here, is apparently rare. The stomach contents of 21 haddock, collected from three stations, were examined. The coelenterates occurred in the stomachs of the fish at only one station and probably reflect a local abundance of this prey item.

The impact of the oil spill on the food habits of various species of groundfish was assessed by surveying the stomach contents. Of the 305 fish stomachs examined, three samples, representing the stomach contents of two species of fish, contained an oil-like material. In two different samples of Atlantic cod collected at Station 29, 25 to 30 miles southwest of the wreck site, oily gammarid amphipods comprised part of the stomach contents. At Station 36 a sample of the stomach contents collected from little skate contained an oily caprellid amphipod. Since 1963 more than 38,000 stomachs, representing 82 species of fish, have been analyzed at the Northeast Fisheries Center and no oil-like materials have previously been reported. Since 1969, a total of 393 little skate and 1706 cod have been examined as part of the routine assessment of fish food habits and, again, no oil-like materials have been identified in the stomach contents (Maurer and Bowman, 1975).

4.1.6 Physiological Effects of Pollutant Stress

This section was contributed by D. Gould and F. Thurberg of NMFS, NEFC, Milford, Connecticut, and are based on samples collected during the second *Delaware II* cruise (DE 77-01).

Two sets of samples of shellfish and fish collected from *Argo Merchant* oil spill area and an adjacent clean area (*Delaware II* cruise 77-01) were examined in the laboratory for physiological disruption. Gill-tissue oxygen consumption rates were measured on ocean scallops (*Placopecten magellanicus*) and horse mussels (*Modiolus modiolus*) from both impacted and control areas. Blood samples from six different species of finfish from both impacted and clean areas were also taken on board the research vessel and returned to the laboratory for hematological analysis. Although the samples in both studies are too small for adequate statistical analysis, the results indicate that both hematology measurements and respiration rates were altered in samples taken from the contaminated areas. Hematological measures showed a disruption of the ionic balance in blood serum and depressed respiration rates (O_2 consumption). The ionic balance of blood serum from winter and yellow-tail flounder caught within the oil spill area was disrupted, and the physiological condition was poorer than that of fish examined from the control area outside the spill. Both measures are useful indicators of disruption of physiological activity possibly caused by the oil spill, and this line of study will be pursued.

Samples from clean areas were taken during the same cruise of brain, kidney, and gonads from 26 teleosts (6 species), and of mantle or hepatopancreas, gills, and gonads from 28 bivalves and crustaceans for biochemical examination. Similar tissues were taken from 24 teleosts and 43 molluscs from oil-impacted areas. To perform exploratory biochemistry on this number of samples of different tissues from different species will take several months. Attempts will be made to search for a possible shift from aerobic to anaerobic metabolism, as well as for induction or repression of enzymes, to serve as metabolic yardsticks that will be both analytically feasible and environmentally significant.

4.1.7 Biological Samples for Hydrocarbon Analysis

The first of two groups of samples were sent to the NOAA National Analytical Facility in Seattle, Washington, for detailed hydrocarbon analysis. The fish and invertebrate species selected for analyses are listed in Table VII-20 in Appendix VII. In addition, the stomach contents of one cod suspected of containing oil were sent.

4.1.8 Phytoplankton Studies

Two phytoplankton tows were conducted by S. French, URI, aboard the *Endeavor* Cruise EN-002. He obtained material from a "clean" area (Station 1) and from a "contaminated" area (Station 2). Since tows are not quantitative, he and P. Hargraves were only able to compare the species composition of large diatoms and dinoflagellates. There was no obvious difference between the two areas. Both were very abundant in Coscinodiscus species, Thalassionema species, Ceratium species, and the tintinnid Stenosemella. Station 2 had small oil droplets in low numbers. There was considerable similarity in species composition with a tow taken in the same area during a previous cruise of the *Endeavor* in early November. On the basis of these two samples, there was no obvious response of phytoplankton to the oil spill. These data are far from conclusive, and future efforts will include quantitative sampling of phytoplankton, estimates of productivity rates, and examination of benthic microbiota.

4.2 Seabird Observations

Observations of seabirds were made both as a part of routine, ongoing activities and in response to the *Argo Merchant* oil spill. The Manomet Bird Observatory (MBO), Manomet, Massachusetts, has been conducting routine studies in the Nantucket and Georges Banks areas since February 1976 by having observers aboard USCG patrol vessels as well as other ships. Most of this effort is supported by private donations and foundation grants, but part of the funding for 1976 was supplied by the U.S. Fish and Wildlife Service (USF&WS). Other seabird observations were also made on all the research cruises conducted in connection with the spill, and the State of Massachusetts instituted a special seabird collection and clean-up effort.

4.2.1 Manomet Bird Observatory Report

L. Loughlin of MBO was fortuitously stationed aboard the USCGC *Vigilant* when the vessel was in the vicinity of the grounded tanker. His observations were funded partly by USF&WS and partly by private donations to MBO. The following is extracted from his report, dated January 3, 1977.

"The vessel usually stayed within 3 miles of the tanker, often much closer. Bird density in the area was generally low, probably due to the lack of fishing activity. The dominant species were Herring Gulls, Great Black-backed Gulls and Black-legged Kittiwakes. Juvenile Herring and Black-backed Gulls outnumbered adults about three to one while most of the Kittiwakes seen were adults. Gannets, again mostly adults, were seen regularly in small numbers. Seen occasionally were Fulmars and Alcids, usually Thick-billed Murres. Table 4-6 gives a daily summary of seabird numbers. Since birds seemed to remain in the area throughout an entire day (many individuals could be recognized by oil patches) census was only taken during the morning hours, while general observations were made in the afternoon. Due to the ship's relatively stationary position and the possibility of birds staying in the vicinity for several days, cruise totals for each species are not given.

"Hardest hit by the oil slick were Herring and Black-backed Gulls. Shortly after oil began to flow from the tanker, birds were seen with small patches on breast and abdomen. Later birds were found with underparts and heads heavily stained (Photograph 47, Appendix III). Late in the patrol, badly oiled gulls, appearing to be weakened, began to land on the *Vigilant*, some accepting food by hand.

"In contrast, Kittiwakes seemed to be affected less by the oil. Few of these birds were seen with oil stains in the early days of the spill and, although the number of oiled birds increased later on, the percentage was much lower than those of Herring Gulls and Black-backs and no badly oiled Kittiwakes were ever observed. This lesser degree of oiling is perhaps reflected in the Kittiwakes' feeding behavior. On several occasions individuals were observed picking objects off the surface of the water with no more than the bill touching. They were never seen feeding in oiled water.

"A few of the Gannets seen were heavily oiled while most seemed to be clean. None of the Fulmars or Murres in the area appeared to be oiled although oiled Murres were reported washing ashore and were therefore obviously affected. Three inshore ducks were sighted and, although their degree of oiling could not be determined, their presence indicates that coastal waterfowl do occasionally wander far from shore and may therefore be threatened by offshore as well as inshore oil spillage.

"Considering the low density of birds in the immediate vicinity of the grounded tanker it would at first appear that damage inflicted by the escaping oil was not very severe. However, oiled birds have been washing ashore daily at Nantucket and Martha's Vineyard, most of these being Murres. This indicates that oil is affecting birds away from the initial site of spilling. On-site oiling and birds stranded on beaches may yet represent only a fraction of the potential devastation. At this time we have no indication as to the amount of damage done 100 or 200 miles "downstream" from the tanker. Contaminated birds driven to the southeast by wind and current will go undetected. Ideally an intensive survey of the birdlife should be made immediately in waters in advance of the oil slick. Such a cruise is at present difficult to arrange. Fortunately, we do have some data on species abundance and distribution in the region during the winter months (see MBO Seabird Report No. 1) and with these we can speculate on the possible remote effects of oil on birds.

Table 4-6. Daily seabird totals and percent oiled at site of *Argo Merchant* December 15 to 24, 1976, as reported by J. Loughlin (total/%)

Species	Date (December 1976)									
	15	16	17	18	19	20	21	22	23	24
N. Fulmer	2/0			1				2/0		
Gannet	37/0	2/0	6	7	1	1	7/28	6/0	1/0	2
Gt. Scaup								1		
Common Eider							1			
Red-breasted Merganser								1		
Skua	1/0	1/0								
Glaucous Gull								1/0		
Iceland Gull									1	
Black-backed Gull	14/0	1/0	13/some	3/many	2	2	45/20	24/40	23/48	32/100
Herring Gull	136/0	15/0	42/some	89/many	11/most	7/most	180/70	68/17	40/75	18/67
Kittiwake	37/0	24/0	33/	44/	43/very few	17/very few	28/4	18/6	12/17	8/25
Razorbill								2/0		
Thick-billed Murre	2/0		4			1				
Hours of Observation	4.8	3.8	4.0	3.5	4.3	4.0	4.5	4.7	4.3	4.0

"As mentioned earlier, the dominant species in the spill area were Herring, Black-backed Gulls, and Kittiwakes. These species were also found to be dominant throughout the Georges Bank-Nantucket Shoals region in February and March although in greater numbers and density. If this is a typical winter pattern of abundance, then large numbers of each of these species are potentially endangered by the oil as it spreads out and moves eastward. A factor which may prevent a large-scale decimation of the gull population is their habit of concentrating in the vicinity of fishing vessels. Since the Coast Guard reported few fishing boats on Georges Bank during December, it is possible that the birds were not hit as hard as might be predicted. However, the frequency of oiled bird sightings on land shortly after the spill indicates a probable high degree of oil contamination at sea. Gannets appear to spend as much time on the water as Herring and Black-backed Gulls and are therefore probably equally susceptible to contact with oil.

"Also seen in smaller numbers were Fulmars and Alcids. Previous cruises show that these two groups winter on the offshore banks. Like gulls, Fulmars have a tendency to follow boats, especially fishing vessels. However, they spend far more time airborne than gulls and might therefore receive less contact with surface oil, minimizing contamination. Alcids, on the other hand, spend almost all of their time on the ocean's surface and are therefore the most susceptible of all the pelagic birds to oil contamination. They are not ship followers and, at present, knowledge of their winter distribution in offshore waters is quite patchy. However, observations from shore during the month of December indicate that there is probably a large number of Alcids off the Massachusetts coast this winter. Several flocks of over a thousand Thick-billed Murres and other Alcids have been sighted off Cape Code. Following the spill, Murres were the most common oiled birds washing ashore on Nantucket and Martha's Vineyard and, since they tend to be found in flocks, it is quite possible that these may have been hit hard by oil contamination, although this will probably never be known for certain."

"Lacking sufficient field data this is merely speculation. Yet, based on information at hand it is probably safe to assume that the *Argo Merchant* disaster will be far-reaching in its effects on pelagic bird life and that most of these effects will go undetected. It is therefore recommended that, until such catastrophes can be prevented, a program whereby the extent of contamination from spilled oil on remote sea birds can be assessed be developed as soon as possible."

4.2.2 Ship Cruise and Overflight Reports

Reports are available from five research cruises that carried trained observers: The *Oceanus* (December 20-21, 28-29, 1976, J. Milliman), the *Delaware II* (December 22-24, 1976, P. Gibb), *Stone Horse* (January 5, 1977, T. Lloyd-Evans), and the *Endeavor* (January 27-29, 1976, L. Gould and N. Houghton). All observers reported that 25 to 75% of the birds seen were fouled, mostly on the breast and abdomen. Herring Gulls and Black-backed Gulls appeared to be the hardest hit, and many boats in the area reported heavily oiled gulls landing on their boats. These birds were often weak and uncharac teristically tame, some accepting food by hand. Other birds seen in the area were Kittiwakes, Gannets, and Murres, but few of these birds were heavily oiled. USCG overflights, generally at an altitude of 500 feet, have not proven successful in bird observations although a single dead gull was seen in the center of a large oil pancake on Christmas Day.

4.2.3 Shore-Based Cleanup Efforts

In general, the density of birds in the immediate vicinity of the spilled oil was low, making it appear that little damage had been inflicted on the bird population. However, a number of birds have been washing ashore regularly on Nantucket and Cape Cod. Approximately 160 birds have been taken to date. This number is not indicative, however, of the true number of birds that washed ashore because of scarcity of beach patrols and the difficulties encountered due to icy conditions, especially on Nantucket. The State of Massachusetts, funded by the Federal On-Scene Coordinator Staff (OCS), instituted a bird collection and cleanup effort coordinated by J. Cardozo, Massachusetts Division of Fisheries and Wildlife. Of the 160 birds taken, 24 were released on January 21, and one remains alive in captivity. All dead birds are being stored at the Sandwich Fish Hatchery, Sandwich, Massachusetts, awaiting autopsy. Live birds collected on Nantucket were taken to Felix Neck Audubon Sanctuary, where heated facilities were available for rehabilitation work. Of the 91 birds brought to Felix Neck, 44 were either dead on arrival or put to sleep immediately, 22 died in rehabilitation, and 15 Murres and 8 Auks were released. One Kittiwake still remains in captivity. Murres are the most common species washing ashore, although few were seen in the area of the *Argo Merchant*. This seems to indicate that many birds are being affected by the oil outside the immediate spill area. Gulls on the other hand, have been seen in the spill area, yet few have washed up on shore (Table VII-21 in Appendix VII). Evidence seems to indicate that gulls are able to withstand much heavier fouling than other bird species. This may be because they have a more readily available food source than other birds, i.e., dumps, which may compensate for the increase in metabolism due to the loss of heat. Birds oiled as a result of the *Argo Merchant* spill have washed ashore as far away as Dartmouth, Nova Scotia. E. Leavey of the Bedford Institute in Dartmouth reported 10 birds of various species having washed ashore in the last 2 weeks. Using gas chromatography techniques, he was able to trace two oiled Black-backed Gulls to the *Argo Merchant* spill.

Assessment of impact of the spill on pelagic bird species will be particularly difficult because of the lack of baseline population studies. Over the last year the Manomet Bird Observatory has begun these studies, and the data collected seem to indicate that this year was exceptional in terms of the number of Alcids (Murres, Auks, Dovekies) present along the Massachusetts coast. The behavioral patterns of these birds make them the most likely species to be hardest hit by the spill. This is borne out in part by the numbers of Murres washing ashore compared with other species. The impact on gull populations may be more easily assessed, because breeding colonies have been censused and population densities are generally known. A plan for a long-term impact study is now being drawn up by NOAA's Marine Ecosystems Analysis Program Office (MESA), and a report is expected by April 15, 1977.

4.3 Observations of Marine Mammals

Coordination of marine mammal observations in the area of the *Argo Merchant* spill began on December 28 as part of the SOR Team research effort with the arrival of B. Baxten from the College of the Atlantic. Provisions were made to carry a trained marine mammal observer on all USCG overflights during the study period, with the goal of establishing species composition, approximate population sizes, and impact, if any, of the oil spill on these populations. Observations were made through January 13, 1977. Although the opportunity did not arise, provisions were made for behavioral studies in the event of direct contact by any marine mammal with a cohesive oil mass.

Since the *Argo Merchant* spill, 43 separate aerial sightings of cetaceans have been made in adjacent areas (Table VII-22 in Appendix VII). The total count of sightings stands at 2 unidentified rorquals, 21 finbacks (Balaenoptera physalus), 7 white-sided dolphins (Lagenorhychus acutus), 13-15 pilot whales (Globicephala malaena), and possibly one grey seal. These limited data showed no bias in the distribution of these animals in relation to the oil. Locations of the sightings are indicated on the daily oil slick maps contained in Appendix IV. Whales were observed within an area of heavy oil concentration on only one occasion, at 1401, December 31. These two finbacks gave no evidence of panic and were not in direct contact with the oil pancakes. No marine mammal was seen in obvious distress or in direct physical contact with oil pancakes or sheen.

No marine mammals were sighted during the December 20 and December 28 research cruises by the WHOI vessel *Oceanus*, nor during the on-scene operations of the USCGC's *Bittersweet* and *Whitefoot*. Three possible finback sightings were reported by J. Loughlin of the Manomet Bird Observatory from the USCGC *Vigilant* in the immediate area of the *Argo Merchant* during the period of heaviest spillage (Table VII-22 in Appendix VII). J. Nicholas of the National Marine Fisheries Service coordinated a marine mammal observations program aboard the second *Delaware II* cruise (DE 77-01) from January 4 to 12. No marine mammals were sighted.

H. Winn coordinated an effort of aerial surveys on December 20 and 22, 1976, to locate marine mammals. Two overflights were made, funded by the Marine Mammals Commission (MM-7A D-032). One grey seal may have been spotted on Muskeget Island on December 20.

4.4 Littoral Zone and Near-Coastal Zone Survey

On Monday, December 27, personnel from MESA, NOAA, assembled a team of intertidal biologists and chemists on Nantucket Island to develop a baseline sampling plan for exposed beaches and inlets of the island that would be vunerable to impact if the spilled oil should come ashore. Members of the team included scientists from the Woods Hole Oceanographic Institution, the Marine Biological Laboratory at Woods Hole, the University of Massachusetts, Northeastern University, and the Energy Resources Company. On Tuesday, December 28, the team went into the field to obtain samples at four localities around the island: two beach sites, a salt marsh site, and an inner bay site. Sediment and biota samples were obtained along the beaches and salt marsh for subsequent evaluation of hydrocarbon content, intersitial fauna, macrofauna, microbial counts and activity, and detrial strand line material. Due to adverse weather, only limited samples could be obtained in Nantucket harbor. Water samples for hydrocarbon analysis were obtained at the salt marsh site.

Appendix V contains a report of the survey, in which samples were analyzed for microbial organisms, chlorophyll, and preliminary identification of living microfauna and macrofauna. The samples were properly preserved for further analysis in the event the oil came ashore. It is unclear at this time if such analyses will be conducted; however, the samples are available as required for comparison with future samples to determine long-term changes on the Nantucket becahes.

The U.S. Geological Survey, under the direction of David Schultz, obtained intertidal samples from Nantucket Island, Ester Island, Tuckernuck Island, Monomoy Island, and Cape Cod. A total of 53 intertidal samples were collected for hydrocarbon analyses, particle size distributions, species identification, and bacteriological studies. All samples are at the Woods Hole Oceanographic Institution.

4.5 Preliminary Surveys of Impact on Fishing Activities

Within the short time available, it has not been possible to properly determine the impact of the *Argo Merchant* oil spill on the local fishing activities, because the effects of the spill may be long-term in nature and cannot be quickly assessed. For example, during the spring spawning season, the larval fry of most fish species spend several days or weeks drifting in the midwater or surface water columns. The spilled oil that entered the water column may have destroyed part of the 1977 year-class of some fish stocks during the two weeks that surface oil covered spawning areas. The results of this destruction of eggs and larvae on stock abundance and potential yields cannot be determined at this time. While it is recognized that finfish can avoid oil-contaminated waters, the effects of oil on spawning bottom, in terms of altered adult behavior, are not known. No hydrocarbons attributable to the *Argo Merchant* have been detected in the bottom sediments except for those found in the immediate vicinity of the sunken bow section (41° 01.4'N, 69° 26.5'W) on February 11, 1977. The effects of this spill upon industry markets and prices are unknown; if, for example, the spill does not reduce the quality of the landings, but the general consensus ashore is that if the landings are contaminated fish prices may be depressed.

Members of the fishing industry believe that the oil in the water column may remain over Georges Bank for the following reason: the area is extremely productive, largely because nutrients are recycled by the currents rather than being swept offshore into the deep water where they would sink from the zone of light and be lost. The currents over the Bank tend to hold material over the area for long periods, recycling it fully to the benefit of marine species. Oil injected into this circulation may thus remain for some time.

However, as the oil concentrations in the water column quickly dropped to essentially background levels, this concern seems unfounded.

In light of these considerations, two separate but related activities are underway to assess the impact of the spill on the local fishing activities. The first is a survey being conducted by the fishermen themselves; the second is documentation of the impact by the port agents of NOAA's National Marine Fisheries Service. Both of these studies are just beginning, and no conclusions have yet been drawn.

4.5.1 Fishermen's Survey

In order to assess the effects of oil on the fishing grounds, the Cape Cod Commercial Fishermen's Coalition has developed a short, one-page form that can be filled out by vessel operators when they are fishing offshore (Figure 4-9). Although the data developed will be rough, nonscientific in a traditional sense, and limited to areas where fish are sought, the information should over a time of several weeks apply to all of Georges Bank and the surrounding waters. The form is kept simple in order to respect the competing time demands upon the fishermen; it merely requests information on location, type of fishery, time of day, date, tide, and weather conditions, and any comments concerning evidence, or lack of evidence, of oil.

The form is currently being distributed to fishermen in Gloucester, Boston, New Bedford, Point Judith, Cape Cod, and elsewhere along the coasts of Massachusetts and Rhode Island. At the moment the following groups are participating and coordinating this effort: The Cape Cod Commercial Fishermen's Coalition, the Massachusetts Inshore Draggers Association, the Atlantic Offshore Fish and Lobster Association, the Gloucester Fishermen's Wives Association, and the New England Marine Industries Council. The forms are being collected by these groups and held, pending choice of agencies and organizations likely to be interested in the data.

The action being taken by the fishermen is at their own initiative and at their own cost, and represents in some degree the interest expressed in assisting others in the research effort. The information obtained with the forms will require initial evaluation and interpretation by the fishermen, but will represent an enormous amount of raw data that must eventually be coordinated and incorporated with other research efforts. Successful and widespread use of these data will go far toward development of a widespread and common data base that will be useful both to operating fishermen and, eventually, to those involved in environmental assessment. New stock assessments may be required, a critical need given imminent extension of jurisdiction on March 1, 1977. Interpretation and summary of the data will require the expertise of individuals most familiar with the fisheries in question, and of fishing vessel operators. Two joint seminars are to be held in February and March 1977 by fishermen and scientists to further refine the results in terms of common understanding and future research programs. At the time of writing, few forms have been returned and analysis has not begun.

OIL SPILL EFFECTS FORM : Tack this to the chart table if you can- space here for four entries

These forms are being given to vessel operators from Gloucester to Rhode Island. Take them with you when fishing and fill them out as you see fit. If you make an area with no sign of oil at all, write that information down and return these forms once a week to your participating group (see below). It is IMPORTANT to indicate a lack of oil just as it is to indicate oil spill evidence. Only through these forms can fishermen and others know in a hurry where the oil is on Georges Bank and surrounding waters. We shall run this program eight weeks - that means eight forms at one a week but hopefully more if there are effects - for example, you may have a form filled out as a result of one tow. Please indicate whether this form refers to TRIP, DAY FISHED, TOW, or other.

LOCATION (Loran, area)				
DATE/TIME OF DAY				
TIDE CONDITION				
WEATHER: State here briefly the wind, seas, etc.				
TYPE FISHERY (for example, fin-fish dragging)				
ENTRY REFERS TO: TRIP, DAY FISHED, TOW, ETC.				
COMMENTS: Evidence of slick, clumps. State color, thickness, area covered Dead or covered birds. Type if you can Fouled gear Fouled Bottom Changes in expected catch Changes in fish behavior No effects seen this day/trip/tow Anything else				

Figure 4-9. Form for fishermen's survey.

4.5.2 NMFS Ports Agents Report

In the NMFS Northeast Region those who are in daily contact with the commercial fishing industry are assessing and documenting the impact of the *Argo Merchant* oil spill on the day-to-day activities of the commercial fishermen through a series of weekly reports to the regional director.

In New England approximately 900 direct interviews were conducted during a total of 4000 fishing trips between December 21 and January 30, at the ports of Portland, Rockland, Gloucester, Boston, and New Bedford, Massachusetts; and Newport and Point Judith, Rhode Island. Only 26 of the interviews indicated an impact of the spilled oil. Five reports indicated direct loss of catch or fouling or loss of gear, while the other 21 reported "oily" birds. All of these incidents occurred in the area to the southeast of the site of the *Argo Merchant* and were reported by a single division of the NMFS Northeast Region.

The following specific problems were reported:

1. A scalloper, fishing very near the wreck area, had his catch and gear fouled by an oil slick; the catch from that tow was discarded as unmarketable.

2. Captains of two vessels, fishing American lobster on the edge of the Continental Shelf, believe that oil fouling of inflatable buoys caused a deterioration of air valves, resulting in a loss of these buoys and consequently the gear they marked. The crew's clothing became fouled during handling of the gear. One lobster fishing vessel had its gear net in the immediate area of the oil drift and, as a result, had to change over the water circulation system from a continuous to a closed one, i.e., instead of taking in water from the area of the oil drift and and contaminating the catch, water from a clean area was used and circulated within the vessel's holding system.

3. Two vessels fishing lobster reported fouled pots, gear, and clothing. Caution had to be taken in removing the lobsters from the contaminated gear.

Other divisions of the Northeast Region filed negative reports.

The collection of data on the oil spill and its effects is, and will be, an ongoing program for all NMFS field employees in the region.

References

Anderson, J. W., D. B. Dixit, G. S. Ward, and R. S. Foster. 1976. Effects of petroleum hydrocarbons on the rate of heartbeat and hatching success of estuarine fish embryos. (F. J. and W. B. Vernberg, eds.) Pollution and Physiology of Marine Organisms, II. Academic Press.

Bowman, R. E., 1975. Food habits of Atlantic cod, haddock and silver hake in the Northwest Atlantic, 1969-1972. Data Report #75-1. Northeast Fisheries Center, NMFS.

Bowman, R. E., R. O. Maurer, and J. A. Murphy. 1976. Stomach contents of twenty-nine fish species from five regions in the Northwest Atlantic. Data Report #76-10. Northeast Fisheries Center, NMFS.

Clarke, G. L., E. L. Pierce, and D. F. Bumpus. 1943. The distribution and reproduction of Sagitta elegans on Georges Bank in relation to hydrographical conditions. Biol. Bull., Vol. 85, No. 3, pp. 201-226.

Colton, J. B., and R. R. Stoddard. 1972. Average Monthly Sea-Water Temperatures Nova Scotia to Long Island, 1940-1959. Serial Atlas of the Marine Environment, Folio 21, Amer. Geogr. Soc., New York.

Hyland, J. L. 1973. Acute toxicity of No. 6 fuel oil to intertidal organisms in the lower York River, Virginia. M.S. Thesis. College of William and Mary (VIMS). 75 pp.

James, M. C. 1925. Preliminary investigations on effects of oil pollution on marine pelagic eggs. Report of the United States Bureau of Fisheries, April 1925, App. 6, 85-92. Report to the Secretary of State by the U.S. Interdepartmental Committee on Oil Pollution of Navigable Waters, 1926.

Jeffries, H. P., and W. C. Johnson II. 1975. Petroleum, temperature, and toxicants: examples of suspected responses by plankton and benthos on the Continental Shelf. In: Effects of energy-related activities on the Continental Shelf (Bernard Manowitz, ed). pp. 96-108.

Kühnhold, W. W. 1969. The influence of watersoluble constituents of crude oils and crude oil fractions on the ontogenetic development of herring fry. Ber. der Deut. Wiss Komm. für Meeresforsch., Vol. 20, No. 2, pp. 165-171.

Kühnhold, W. W. 1972. Untersuchungen über die Toxizität von Rohölextrakter und emulsionen auf Eier und Larven von Dorsch und Hering. (Investigations on the toxicity of crude oil extracts and dispersions on eggs and larvae of cod and herring). Ph.D. Thesis. University of Kiel, FRG.

Kühnhold, W. W. 1974. Investigations on the toxicity of seawater-extracts of three crude oils on eggs of cod (Gadus morhus L.), Ber. der Deut. Wiss. Komm. für Meeresforsch., Vol. 23, pp. 165-180.

Longwell, A. C. 1976. Chromosome mutagenesis in developing mackerel eggs sampled from the New York Bight. MESA-7, April. 61 pp.

Maurer, R. O., and R. E. Bowman. 1975. Food habits of marine fishes of the Northwest Atlantic. Data Report #75-3, Northeast Fisheries Center, NMFS.

Mironov, O. G. 1969a. The effect of oil pollution upon some representatives of the Black Sea zooplankton. Zoologicheskii Zhurnal, Vol. 48, No. 7, pp. 980-984. (English Translation).

Mironov, O. G. 1969b. Viability of larvae of some crustaces in sea water polluted with oil-products. Zoologicheskii Zhurnal, Vol. 48, No. 11, pp. 1734-1737.

Parker, C. A., M. Freegarde, and C. G. Hatchard. 1970. The effect of some chemical and biological factors on the degradation of crude oil at sea. Seminars on Water Pollution by Oil. Aviemore/Scott 4-8.5.70, paper 17.

Wigley, R. L. 1956. Food habits of Georges Bank Haddock. Special Scientific Report--Fisheries #165.

Wigley, R. L., and R. B. Theroux. 1965. Seasonal food habits of highlands ground haddock. Trans. Am. Fish. Soc., Vol. 94, pp. 243-251.

5. CONCLUSIONS

The intensive studies conducted in response to the *Argo Merchant* oil spill have resulted in some significant findings, not only on the fate of the oil from the tanker, but also on the behavior of spilled oil in general.

Preliminary chemical analyses for oil content have been completed for all water and sediment samples taken up to February 12, 1977, by cooperating scientists. Selected samples have been sent to the NOAA National Analytical Facility in Seattle, Washington, for more detailed study. Biological studies primarily based on the six stations occupied during the first cruise of the *Delaware II* (DE 76-13) have been reported by NMFS scientists. However, the chemical and biological studies are not complete. Further analyses are being conducted by all concerned to complete the assessment of the fate and impact of the oil spilled from the *Argo Merchant*. With these cautions in mind, the following *preliminary findings* are presented and supported by this report.

Notable among these findings are:

(1) The oil from the *Argo Merchant* stayed on the ocean surface with the exception of some of the "cutter stock," which entered the water column, and an as-yet undetermined amount of whole oil that was mechanically worked into the bottom in the immediate vicinity of the wreckage. The cutter stock, which comprised 20 percent of the oil, was found in the water column in concentrations up to 250 parts per billion. The highest levels were only found beneath fresh oil slicks. After a few days, these levels were reduced to background levels by turbulent mixing.

(2) Oil in significant amounts has not been found in the sediments to date, except within 10 miles of the bow section where it has been found in concentrations up to 100 parts per million.

(3) Most of the oil remained on the surface and moved offshore under the influence of the prevailing west winds. Surface oil was never observed north of 41°21' or west of 70°10', nor was it observed within 15 miles of any land. Operational modeling efforts were successful in predicting the offshore movement of the surface oil primarily because the movement was controlled by predominantly offshore winds while the complicated circulation of near-shore areas and Nantucket Shoals played only a minor role.

(4) There is evidence of oil contamination in fish, shellfish, ichthyoplankton, and zooplankton populations in the area of the spill. Mortalities of developing cod and pollock embryos in eggs contaminated with oil were observed. No. 6 fuel oil caused significant mortalities of cod embryos in laboratory experiments conducted by NMFS and collaborating scientists of EPA and the University of Kiel. Noticeable decreases in the abundance of sand launce larvae were observed in the spill zone that may have been caused by oil. Large numbers of zooplankters, which are an important food of larval and adult fish, were contaminated with petroleum hydrocarbons similar to No. 6 fuel oil, indicating that an important pathway in the food web of the Nantucket Shoals ecosystem was impacted. The extent of this impact is under

investigation. Much of the oil in the copepods was in the form of fecal pellets. These pellets are excreted into the water column, settle to the bottom, and may be concentrated in benthic filter-feeders (mussels, scallops, quahogs). Adverse physiological effects were also observed in reduced respiration of scallops, mussels, and in an ionic imbalance of blood serum of blackback and yellowtail flounders. The implications of the above results for long-term effects are unclear. Additional extensive surveys and laboratory tests be required to clarify preliminary findings.

(5) The No. 6 fuel oil from the *Argo Merchant* formed pancakes of oil which tended to increase in thickness as they aged. These pancakes were observed to have flat bottoms and they did not appear to be tapered towards their edges. The surface area impacted by oil was not solidly covered by a continuous film of oil but rather by thick pancakes, very thin oil film (sheen) and large open areas of water. Several direct measurements of the velocity of the pancakes of oil relative to the surface water were obtained which indicate that this differential velocity is about 1 percent of wind speed in a downwind direction. The oil sheen appeared to be generated by the oil in the pancakes and moved at a slightly lower speed.

(6) Sufficient data were collected during the oil spill to allow the generation of a data set which can be used for hindcasting the oil movement. The collected data include meteorological observations, current observations at several locations in the spill area, a time history of the area covered by oil, as well as data on the amounts and fractions of the oil which entered the water column as a function of time and space. Analyses of these data will lead to the development of improved algorithms describing the fate of oil. These algorithms can then be incorporated into predictive models.

5.1 Oil Transport

Under the influence of the predominant westerly winds and the wind-induced surface currents, the oil spilled from the *Argo Merchant* moved in an east-southeast direction from the site of the wreck on Nantucket Shoals out past the Continental Shelf and became a part of the general circulation of the North Atlantic Ocean. All indications are that the remaining oil will not sink and will be present on the ocean surface for some time. This oil has by now become a part of the "standing stock" of tar balls floating in the North Atlantic. As such, they will tend to weather until the exterior surface develops the characteristics of asphalt. The hard outer surface will act as settling surfaces for barnacles, etc., while the interior of the larger tar balls will retain much of the fluid consistency of the original straight-run No. 6 fuel oil.

Each day that the oil moved off the Continental Shelf and into the Atlantic circulation pattern, the weather became less of a forcing factor and the slick movement was dominated by baroclinic (general oceanic) currents. The waters over Nantucket Shoals and Georges Bank during the last two weeks of December were vertically homogeneous, and the general westerly current pattern described in BLM's EIS for Georges Bank did not appear to be established. In actual fact, in addition to the measured wind drift of the oil, a net surface current on the order of 0.6 knot in a southeasterly direction was observed during that period. In less than 50 m of water, it appeared that the net currents were responding well to the wind. The pancakes of oil emanating from the wreck were observed to build up in thickness as they moved away from the wreck. After 1 or 2 weeks of movement, thick patches of oil which were originally 1 1/2 - 2 inches became 5 to 10 inch thick patches. The ethereal "3%" wind factor that has been tossed about freely for years is now being pinned down. Patches of *Argo Merchant* oil were measured moving relative to the water at 0.7 to 1.1% of the wind speed, for wind speeds of 10 to 30 knots and oil thickness of 1 to 2 inches. The thinner sheens covering much of the sea surface appear to be "fed" by the thick patches so that their movement is limited to the 1% wind factor as well. This wind factor probably represents the effect of energy transfer from waves interacting with the oil. There is a wind-induced surface current, amounting to about 2% of the wind speed, that also needs to be considered when predicting oil movement using subsurface current information. However, when drift cards or bottles are the source of current data, the "3%" figure is excessive as a wind factor and should be replaced by a figure of about 1%.

A large amount of information has been gathered which has been and will be of value in improving both operational forecasting of real oil spill trajectories and statistical models of oil spills from a "risk analysis" point of view. It is inadequate to use look-up tables for currents combined with statistical models of wind, or vice-versa. In the near-shore environment, the winds and currents are too highly correlated for the above approach to be adequate. Moreover, for short-term forecasting, tidal currents as well as wind drift should be included for realistic output. For real-time forecasting, the value of accurate slick maps cannot be understated. Accurate measurements of oil/water differential velocities, the observation that pancakes build up in thickness rather than disperse, and the underslick cinematography will all serve to improve the state-of-the-art in oil spill modeling.

5.2 Fate of the Oil

The *Argo Merchant* No. 6 fuel is composed of about 80% straight-run No. 6 and about 20% light distillate fuel (which was used as a "cutter stock" to make the oil easier to handle). It now appears that some of the cutter stock entered the water column, at maximum levels on the order of 250 parts per billion. Highest concentrations were found under fresh oil slicks though not in the near-surface samples, but at depths of 2-3 m. Concentrations decreased after a few days to background levels through turbulent mixing of the homogeneous water column. More definitive chemical analyses are being conducted to verify these findings.

Severe artifical weathering of a cargo sample indicated that the straight-run No. 6 component retains a positive buoyancy and will not sink unless aided. The oil found in the vicinity of the wreckage is associated with shell fragments in the sediments and would otherwise rise due to its natural buoyancy. The U.S. Navy divers reported no visible oil on the bottom approximately 1/4 mile from the wreck on December 23, and their film supports this finding. Since the currents at the wreck site are primarily tidal, the oil had passed over the spot checked by the divers twice a day for 7 days prior to the dive. Microscopic examination of 25 sediment samples from the *Delaware II* cruises also indicated the absence of visible oil. Thin-layer chromatographic analyses of sediment samples have indicated very low petroleum hydrocarbon (PHC) levels with the majority of the samples exhibiting less than 1 part per million PHC's. Sediment samples from the *Oceanus* cruises indicated appreciable levels, up to 5 ppm, of PHC's. The highest levels were found at *Oceanus* stations 1 and 5 which are located to the west of Nantucket Shoals in an area of mud bottom. The oil slick was never within 20 miles of these stations. Additional analytical work confirmed that the oil in these samples is not from the *Argo Merchant*.

Preliminary evidence indicates that oil from the *Argo Merchant* is being cycled through the food web of the Nantucket Shoals ecosystem. Large numbers of zooplankters which are an important food of larval and adult fish are contaminated with oil. The presence of petroleum hydrocarbons in zooplankton indicates that an important pathway between plankton, necton, and benthos is contaminated. The oil can be concentrated in the tissues of shellfish as they feed on fecal pellets of the zooplankton. The significance of the cycling of the *Argo Merchant* oil through the food web has not been fully assessed and will be the subject of additional survey and experimental efforts.

Oil was found in the bottom sediments near the bow section on February 11, 1977. The area where the bow section dragged is contaminated with *Argo Merchant* oil, presumably from physical contact with the bow section. The area encompassed by this contamination is not known at present, but resuspension of oiled sediments in the area appears to be transporting the oil to the southwest. Another *Endeavor* cruise was conducted February 21-25 to establish the magnitude and extent of the oil contamination around the wreckage itself.

"Tar balls" reported washing ashore on southwest Nantucket Island in March appeared to have come from a recent spill, and analysis is under way to determine whether the tar comes from crude or refined petroleum. However, this will not be able to establish whether the tar originated with oil spilled by the *Argo Merchant* or with another spill of No. 6 fuel oil.

5.3 Biological Effects

Although it is difficult at this time to assess the possible damage to the Georges Bank-Nantucket Shoals ecosystem, some evidence has been found of oil contaminating several species of fish, shellfish, and plankton in the area of the oil spill.

Mortalities were observed in developing cod and pollock embryos in eggs collected from the area. Greatest damage was observed in eggs collected closest to the *Argo Merchant*, and genetic damage was greater in pollock eggs than cod eggs. In one sample taken near the spill, 98 percent of the pollock eggs sampled were dead or moribund, as against 64 percent of the cod eggs in the same sample. Averaged over all stations sampled, pollock embryos showed 46 percent mortality or moribundity, with cod embryos running about 20 percentage points less. These observed mortalities need to be evaluated against the high levels of naturally occurring egg mortality. Efforts are now underway to assess the impact of these mortalities on the cod and pollock stocks of the Georges Bank-Nantucket Shoals area. Results from laboratory studies conducted jointly with EPA, Narragansett, and Dr. Walter Kuhnhold, visiting scientist with NMFS from the University of Kiel, Federal Republic of Germany, have shown that No. 6 fuel oil will cause mortalities and retarded development of cod eggs at concentrations between 100 and 500 parts per billion. They also report that dying eggs sink to the bottom, indicating that survey collection of moribund eggs may be seriously underestimating actual population mortalities.

Zooplankton food of larval and adult fish was also contaminated with *Argo Merchant* oil. Copepods were observed with oil on feeding appendages, in alimentary tracts, and on the surface of the body. In addition, oil similar to *Argo Merchant* oil was in alimentary tracts and fecal pellets of those species collected within and adjacent to the spill area, indicating an important contaminant pathway from the spill into the food web of Nantucket Shoals. Oil ingested by copepods could be concentrated as it moves through the food web as fecal pellets from contaminated zooplankton are ingested by filter feeders, or if zooplankton containing oil are eaten directly by predators including larval and adult fish. *Argo Merchant* oil is persisting in the food web; as recently as February 23 1977, copepods were collected which, under microscopic examination, contained petroleum residues.

Substantially smaller numbers (80% less) of larval sand launce at stations sampled within the spill zone, compared to outside the zone, may have been caused by the toxic effects of oil. Although not a commercially important species at this time, the sand launce is an important food of fish, including cod, haddock, pollock, and hake. It is also eaten in large quantities by whales and porpoises. The effect of these lower numbers of larvae on the production of sand launce in the Nantucket Shoals and Georges Bank area is presently under study by NMFS scientists of the Northeast Fisheries Center.

Scientists of NMFS working at the Milford Laboratory detected imbalances in the normal physiological responses of mussels and scallops collected from the waters contaminated with oil. Respiration rates were lower than in samples collected outside of the spill zone. Also, the ionic balance of blood serum is blackback and yellowtail flounders was lower than in control specimens collected from outside the spill area.

It is not possible at this time to extrapolate from the oil-caused mortalities and sublethal effects observed to the impact on the productivity of the Nantucket Shoals-Georges Bank ecosystem. Additional sampling and experimentation over the next year is required for an adequate assessment of damage.

Twenty-two samples of fish and invertebrates have been sent to the NOAA National Analytical Laboratory in Seattle for complete hydrocarbon analyses. Pending the outcome of those tests, a second group of samples may be sent.

Of the seabirds affected by the spilled oil, observed mortality was highest among Murres. Lack of adequate offshore sampling information precludes any definitive conclusions on the extent of impact.

Marine mammals did not appear to be affected by the oil in the few cases where they were seen in the vicinity of oil. However, as with the seabirds, these findings are based on very limited sampling.

It should be noted that no significant adverse effects have been reported by fishermen trawling off the Rhode Island and Massachusetts coasts. In 900 interviews conducted by NMFS Port Agents, only 26 reported damage, mostly to sea birds. Only two fishermen indicated problems associated with the fouling of gear in oil slick waters.

6. ONGOING ACTIVITIES

The field phase of the research activities described in this report thus far have been completed. There are, however, a number of ongoing activities which are discussed below.

6.1 Physical Processes

The U.S. Coast Guard will continue the mapping of the oil released from the *Argo Merchant* until stopped by the Federal On-Scene Coordinator (OSC) when he determines that it is no longer necessary.

The National Weather Service will continue to provide support to the OCS and the community at large in the form of forecasts, warnings, etc. In the event that a "blowup" of the wreck is planned, the operation will be expanded to include 10-day outlooks, delegation of a Weather Service operational representative to collocate with the OSC, and expanded and more numbeous forecasts. It has been estimated that operational support may be necessary for surveillance, diving, and other activities through mid- 1977.

The data collected by the installed current meters will be retrieved and analyzed by the organizations which supplied them. These data will be very useful to the modelers concerned with forecasting spilled oil movement for validating intermediate portions of their models and to refine them to the local and other areas.

The outputs generated by each of the models described in Section 2.3 will be further analyzed in efforts to improve their accuracy in light of the new information acquired.

6.2 Chemical Processes

Selected water, sediment, and fish samples will be analyzed at the NMFS National Analytical Facility by gas chromatograph-mass spectrometer techniques to complete the studies on the fate and weathering of the *Argo Merchant* oil. In addition, samples will continue to be processed as the *Endeavor* returns to the scene of the wreckage to measure the extent of bottom contamination in that area.

6.3 Biological Processes

The *Argo Merchant* oil spill in its passage over Nantucket Shoals and southeast Georges Bank encroached on the spawning grounds of cod, haddock, pollock, herring, flounders (yellowtail, blackback, four-spot, sanddab) and important scallop and silver hake fishing grounds. Considering the importance of the area, fish, shellfish, ichthyoplankton and benthos assessments will be made by the NMFS Northeast Fisheries Center through extension and augmentation of ongoing MARMAP surveys during the next 18 months to determine the actual or potential impact. It is intended through Center reprogramming and temporary reassignments to complete six to nine MARMAP surveys over the area of the spill. These will provide important statistical infomation on species composition and relative abundance, but these data will provide little substantive information on the sublethal effects of the spill on the "health" or condition of the stocks.

If the impact of petroleum hydrocarbons on the fisheries resources of the area is to be assessed with any reasonable probability of success, it is essential to process selected species of fish, shellfish, benthos and ichthyoplankton for genetic damage, disruption of normal physiological processes, pathobiological conditions, and for levels of petroleum hydrocarbon contaminants.

Plans have been developed to carry forward a comprehensive long-term assessment, which will include the following studies:

Two NMFS cruises are planned to assess changes in populations of important benthos and shellfish. Specimens of several shellfish species will be collected for evidence of pathological conditions and toxic effects from petroleum hydrocarbons in the environment.

Expanded monitoring of larval and juvenile fish will encompass the area of the oil spill to assess changes in population levels.

Ongoing cooperative efforts between NMFS (Drs. Laurence and Kuhnhold, Narragansett) and EAP (Jackim and Lefcourt, Narragansett) will be augmented to determine effects of No. 6 fuel oil on pelagic fish eggs and larvae. In addition, eggs and larvae of cod, and other demersal species such as winter flounder will be used to test for responses of eggs and larvae to treatment with "surrogate" *Argo Merchant* oil.

Chromosomal studies of fish eggs and embryos (Dr. Longwell, NMFS, Milford) will be extended to examine fish species in the Georges Bank-Nantucket Shoals area. Genetically based egg mortality occurring in populations fishes will be assessed and the relative importance of hydrocarbons and natural environmental factors inducing lethal chromosome errors in developing fish eggs will be investigated.

Specimens of tissue from selected fish and shellfish species from clean and impacted areas will be analyzed (Rosenfield, NMFS, Oxford) for evidence of abnormalities, tissue, and cellular diseases. Also, incidence of anatomic lesions in fish and shellfish from clean and contaminated areas will be monitored.

Analyses of tissue samples (Gould and Thurberg, NMFS, Milford) from fish and shellfish (e.g., ocean scallops and horse mussels) will continue to identify indicators of the physiological and biochemical health of the organism (such as hematology and respiration rates, shifts in metabolic pathways, induction or suppression of enzyes.

Hydrocarbon analyses on selected fish and shellfish (adults, juveniles and embryos) will continue at the NOAA National Analytical Facility in Seattle, Washington.

APPENDIX I

Contributors and Participants

Spilled Oil Research Team

James S. Mattson, Chief Scientist
CEDDA, EDS, NOAA, Washington, D.C.

Craig Hooper, Program Manager
OCSEAP, ERL, NOAA, Boulder, Colorado

Jerry A. Galt, Team Leader
PMEL, ERL, NOAA, Seattle, Washington

Peter L. Grose, Team Leader
CEDDA, EDS, NOAA, Washington, D.C.

David M. Kennedy, Team Leader
Arctic Project Office, ERL, NOAA, Fairbanks, Alaska

Rod Swope, Team Leader
OCSEAP, ERL, NOAA, Juneau, Alaska

Elaine I. Chan, East Coast Team
CEDDA, EDS, NOAA, Washington, D.C.

Gary Hufford, East Coast Team
Research and Development Center, USCG, Groton, Connecticut

Sue Lease, Boulder Team
OCSEAP,ERL, NOAA, Boulder Colorado

Dick Feely, West Coast Team
PMEL, ERL, NOAA, Seattle, Washington

Marilyn Pizzello, West Coast Team
PMEL, ERL, NOAA, Seattle, Washington

John Janssen, Fairbanks Team
Department of Environmental Conservation, State of Alaska

Alan Kegler, Juneau Team
Department of Environmental Conservation, State of Alaska

Sue Anderson, Juneau Team
OCSEAP, ERL, NOAA, Juneau, Alaska

Department of Transportation (DOT)

U.S. Coast Guard (USCG)

Captain Lynn Hein, Federal On-Scene Coordinator
1st District, Boston, Massachusetts

Cmdr. Charles Morgan
Oceanographic Unit, Washington, D.C.

LCmdr. Barry Chambers, Commanding Officer
Atlantic Strike Team, National Strike Force
Elizabeth City, North Carolina

Scot Fortier
Research and Development Center, Groton, Connecticut

LCmdr. Ivan Lissaur
Research and Development Center, Groton, Connecticut

Cmdr. Richard Rybacki, Assistant Director
Research and Development Center, Groton, Connecticut

Joseph Deaver
Oceanographic Unit, Washington, D.C.

Bill Anthony
Oceanographic Unit, Washington, D.C.

Richard Jadamec
Research and Development Center, Groton, Connecticut

Lt. David Freydenlund
Oceanographic Unit, Washington, D.C.

Bruce Thompson, MST
Research and Development Center, Groton, Connecticut

Cmdr. Ian Cruikshank, Commanding Officer
USCGC *Vigilant*, New Bedford, Massachusetts

LCmdr. J. F. Overath, Commanding Officer
USCGC *Bittersweet*, Woods Hole, Massachusetts

LCmdr. Bebeau, MSO
USCGC *Bittersweet*, Woods Hole, Massachusetts

National Oceanic and Atmospheric Adminstration (NOAA)

Environmental Data Service (EDS)

Fredrick Godshall, CEDDA, Washington, D.C.
Joseph Bishop, CEDDA, Washington, D.C.
Jack Carlile, CEDDA, Washington, D.C.
Bob Dennis, CEDDA, Washington, D.C.
Katherine Kidwell, CEDDA, Washington, D.C.
George Heimerdinger, NODC, Woods Hole, Massachusetts

Environmental Research Laboratories (ERL)

Lou Butler, MESA, Boulder, Colorado
Herb Curl, MESA, Boulder, Colorado
John Robinson, MESA, Boulder, Colorado
Edward P. Meyers, MESA, Boulder, Colorado
David Friis, OCSEAP, Boulder, Colorado
Rosalie A. Redmond, OCSEAP, Boulder, Colordo
Don Swift, AOML, Miami, Florida

NOAA Data Buoy Office (NDBO)

James Winchester, Director, Bay St. Louis, Mississippi
Dewain Clark, Bay St. Louis, Mississippi
Jay Harris, Bay St. Louis, Mississippi

National Marine Fisheries Service (NMFS)

Frank Riley, Gloucester, Massachusetts
Dusty Gould, Milford, Connecticut
Arlene Longwell, Milford, Connecticut
Fred Thurberg, Milford, Connecticut
Donna Busch, Narragansett, Rhode Island
Walter Kühnhold (visiting expert from University of Kiel, FRG)
Ray Maurer, Narragansett, Rhode Island
Carolyn Rogers, Narragansett, Rhode Island
Kenneth Sherman, Narragansett, Rhode Island
Loretta Sullivan, Narragansett, Rhode Island
Wally Smith, Sandy Hook, New Jersey
William D., MacLeod, Seattle, Washington
Ray Bowman, Woods Hole, Massachusetts
Henry Jensen, Woods Hole, Massachusetts
George Kelly, Woods Hole, Massachusetts
Richard Langton, Woods Hole, Massachusetts
Roland Wigley, Woods Hole, Massachusetts
Redwood Wright, Woods Hole, Massachusetts

National Weather Service (NWS)

Celso Barrientos, Silver Spring, Maryland
Anthony Tancreto, Boston, Massachusetts

Environmental Protection Agency (EPA)

Carl Eidam, Region 1
Paul Lefcourt, Narragansett, Rhode Island
Richard Pruell, Narragansett, Rhode Island
Dianne Everich, Narragansett, Rhode Island
Eugene Jackim, Narragansett, Rhode Island

National Aeronautics and Space Administration (NASA)

Langley Research Center

John P. Mugler, Jr., Team Leader, Hampton, Virginia
Wendell G. Ayres, Hampton, Virginia
David Bowker, Hampton, Virginia
John T. Shuttles, Hampton, Virginia

Wallops Flight Center

John D. Oberholtzer, Wallops Island, Virginia
Chester L. Parsons, Wallops Island, Virginia

Department of the Interior (DOI)

Bureau of Land Management (BLM)

Ken Berger, New York, N.Y.

U.S. Geological Survey (USGS)

Brad Butman, Woods Hole, Massachusetts
David Folger, Woods Hole, Massachusetts
David M. Schultz, Woods Hole, Massachusetts
Richard A. Smith, Reston, Virginia
J. Slack, Reston, Virginia
T. Wyant, Reston, Virginia

Department of Defense (DOD)

U.S. Navy (USN)

Chief Richard Johnson, Atlantic Fleet Audio Visual Command
Larry Cregger, Atlantic Fleet Audio Visual Command
Ken Hess, Atlantic Fleet Audio Visual Command
Troy Gruber, Atlantic Fleet Audio Visual Command
David Shonting, Naval Underwater Systems Center

Commonwealth of Massachusetts

Division of Fisheries and Game

James Cardozo, Boston, Massachusetts

Research and Academic Institutions

Manomet Bird Observatory (MBO)

Kathleen Anderson
James M. Loughlin

Marine Biological Laboratory (MBL)

John E. Hobbie
B. J. Peterson
George Woodwell

University of Rhode Island (URI)

Chris Brown, Chemistry
Peter Cornillon, Ocean Engineering
Robert Gordon, Ocean Engineering
Lisa Gould, Zoology
Remy Halm, Ocean Engineering
Eva J. Hoffman, Graduate School of Oceanography
Christopher Noll, Ocean Engineering
James G. Quinn, Graduate School of Oceanography
Robert Sexton, Graduate School of Oceanography
Malcolm Spaulding, Ocean Engineering
Mason Wilson, Mechanical Engineering
Howard Winn, Graduate School of Oceanography

University of Southern California (USC)

Ronald Kolpack, Geology

Massachusetts Institute of Technology (MIT)

Jerome H. Milgram

Woods Hole Oceanographic Institution (WHOI)

Robert Beardsley
John Farrington
Peter Fricke
Robert A. Frosch
John Milliman
Phil Richardson
Howard Sanders
John Teal

Contractors

Aero-Marine Services, Inc. (BLM subcontract)
Development Sciences, Inc. (Office of Sea Grant, NOAA, contract)
Discover Flying (SOR contract)
EG&G (BLM contract)
New England Air-Photo Association (EPA contract)
Raytheon (BLM contract)

Individuals

Ben Baxter, marine mammal observer
Barbara Morson, marine bird observer

APPENDIX II

Chronology

SEVENTEEN-DAY SUMMARY: DECEMBER 15 TO 31, 1976

Weather Conditions (Daylight)	Air: U.S. Coast Guard cutters on station recorded hourly meteorological data. Sea: Sea conditions recorded hourly by U.S. Coast Guard cutter.
Argo Merchant	One of the largest oil spills in American history; 7½ million gallons of oil spilled.
USCG Operations	Unable to save the *Argo Merchant* despite heroic efforts. Water samples collected daily by USCGC's *Bittersweet* and *Vigilant*. Forecasting should improve after analysis of *Argo Merchant* data.
Overflights	Visual and infrared mapping of plume. Mammal sightings. Oil and water current measurements. Drift cards dropped as early warning systems. Extensive photographic record.
NOAA/USCG SOR Team Operations	Coordination of research activities. Measurements to document the fate of *Argo Merchant* oil.
Other Operations	Normal wintering whale and porpoise populations established. No noticeable reaction to spill. Movies taken by U.S. Navy of morphology of the underside of the slick and bottom. No visible oil. Eleven current meters deployed at 6 moorings.
Ship Cruises	During nine cruises, 210 water samples, 34 sediment samples, and 40 intertidal samples obtained. Plankton samples and organisms also collected. No confirmed reports of visible oil.
Spill Characteristics	Intense mapping of spill. "Thickening" phenomenon data available for research on oil weathering. Oil transport and dispersion data established. Basis for long-range research program established.
Coordination Meetings and Briefings	Research activities coordinated by participating scientists.

Wednesday, December 15, 1976

Weather Conditions (Daylight)	Air:	Medium visibility. Overcast. High southwest winds at 35 knots in late afternoon, veering toward east winds at 4 knots toward midnight.
	Sea:	Large, 10-foot, waves and swells.
Argo Merchant	0700:	Ship aground on Nantucket shoals. 40° 55'N 69° 33'W
	1115:	Flooding of engine rooms continues.
	1340:	Discharge of oil observed by USCG.
	1630:	Twenty crewmen removed.
USCG Operations	0700:	Distress call received.
	1115:	Strike force boards *Argo Merchant*.
	1115:	USCGC *Sherman* on scene; remains entire day.
	1315:	USCGC *Vigilant* on scene; remains entire day.
	Plans begun for operations forecasting of oil drift.	
Overflights		
NOAA/USCG SOR Team Operations	1300:	Notified by NMFS.
	1630:	Responds.
	2100:	On site.
Other Operations		
Ship Cruises		
Spill Characteristics	Unknown.	
Coordination Meetings and Briefings		

Note: All times are Eastern Standard Time.

Thursday, December 16

Weather Conditions (Daylight)	Air: Low visibility. Northeast winds at 13 knots. Overcast. Ceiling 2000 feet, dropping to 500 feet in afternoon. Sea: Calm. Strong currents. Small, 1-foot, waves.
Argo Merchant	0400: Pumping (dewatering) of engine room. 2300: Ship abandoned. Evacuation of all personnel. Ship bearing 315°.
USCG Operations	1547: Assumes full control and responsibility for *Argo Merchant*. 2100: Begins operational forecasting of oil drift. 1600-1625: USCGC *Bittersweet* on scene. USCGC's *Sherman* and *Vigilant* on scene entire day.
Overflights	0930: Cessna-182 deploys current probes and dye markers. 1500: Second mission aborted because of low visibility.
NOAA/USCG SOR Team Operations	Aboard Cessna-182.
Other Operations	
Ship Cruises	
Spill Characteristics	Oil 2 miles north to south and 4 miles east to west. Oil moving west. Streak of oil; bearing about 240°.
Coordination Meetings and Briefings.	2300: University of Rhode Island coordination meeting with SOR Team at Hyannis.

Friday, December 17

Weather Conditions (Daylight)	Air: Medium visibility. Overcast. Rain and snow. West medium winds at 17 knots. Sea: Small, 2- to 4-foot, waves and swells.
Argo Merchant	41° 1.0 69° 27.0' vessel pivoting counterclockwise. Bulkheads and deck buckling. List 5-10¼ to starboard.
USCG Operations	0236: USCG *Bittersweet* on scene with boom; remains entire day. 0430-1245: Barge on scene. 1045: USCGC *Sherman* departs. USCGC *Vigilant* on scene entire day.
Overflights	1145: HU-16E. Current probes. Video tape. Mapping.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E.
Other Operations	
Ship Cruises	
Spill Characteristics	Heavy plume of 95 to 100 percent oil extends northwest for 5 miles, then west for 3½ miles. No sheen or slick.
Coordination Meetings and Briefings	1200: University of Rhode Island coordination meeting ends. 1400: Planning meeting with Woods Hole Oceanographic Institution (WHOI).

Saturday, December 18

Weather Conditions (Daylight)	Air: High visibility. Scattered clouds. High winds west-northwest at 30 knots. Sea: Five- to 8-foot waves.
Argo Merchant	41° 02.0'N 69° 27.5W Bearing 0800-250°, 1200-240°, 1700-244° Ship listing 15° to starboard. Pitch and yaw movement.
USCG Operations	0600: USCGC *Bittersweet* and first barge depart. Second barge in area. 1035: Strike force boards *Argo Merchant*. 1513: Strike force departs. USCGC *Vigilant* on scene entire day.
Overflights	0600: PA-23. Current measurements. 0837: HU-16E. Infrared mapping. Surface markers. Deployment of current probes, dye markers, and drift cards.
NOAA/USCG SOR Team Operations	Personnel aboard PA-23 and HU-16E.
Other Operations	Oil sample taken by *Milgram* from tanker cargo. AMSI overflight.
Ship Cruises	
Spill Characteristics	Globs of oil drifting from starboard side of *Argo Merchant* and forward of her bow. "Pancakes" observed 27 miles east of ship. Heavy plume forming horseshoe path 7½ miles long.
Coordination Meetings and Briefings	WHOI *Oceanus* cruise coordination meeting at Woods Hole.

Sunday, December 19

Weather Conditions (Daylight)	Air: High visibility. Thin overcast. Medium west winds at 18 knots. Sea: Calm. Small waves and swells.
Argo Merchant	Ship bearing 239° Position 41° 02.0'N 69° 27.5'W List 15° to starboard.
USCG Operations	1400: Strike force boards *Argo Merchant*. 1430: Strike force departs. 1645: Rigging of fenders and anchors. USCGC *Vigilant* on scene entire day. Mooring systems loaded.
Overflights	0900: NASA C-54. 1000: EPA oil survey. 1400: H-3. Mapping. Current probes. Drift cards. Dye markers. 1500: Cessna-182. Current probes. Drift cards. Dye markers.
NOAA/USCG SOR Team Operations	Personnel aboard H-3 and Cessna-182.
Other Operations	
Ship Cruises	
Spill Characteristics	Oil coming off bow of *Argo Merchant*. Heavy sickle-shaped plume extending 16 miles, with an average width of 2 miles. "Pancakes" observed and sampled.
Coordination Meetings and Briefings	

Monday, December 20

Weather Conditions (Daylight)	Air: High-to-medium visibility. Scattered clouds. Medium south winds at 18 knots. Sea: Small waves.
Argo Merchant	Unchanged.
USCG Operations	0036: USCGC *Spar* on scene. 0745: Strike force boards *Argo Merchant*. 1625: Strike force departs. USCGC *Vigilant* on scene entire day. Fenders, anchors and marker light rigged. Mooring buoys set.
Overflights	0930: H-3. Mapping. Current probes. Drift cards and dye markers. Smoke bomb. 1430: Cessna-182 terminated by weather.
NOAA/USCG SOR Team Operations	Personnel aboard H-3, Cessna-182, and WHOI *Oceanus* cruise.
Other Operations	
Ship Cruises	1430: WHOI *Oceanus* cruise 19 begins. Water and sediment sampling. Biological investigations.
Spill Characteristics	A great deal of oil coming off stern of *Argo Merchant*. Main plume banana-shaped, 3½ miles wide and 16 miles long. Sheen 7 miles long attached to southeast edge.
Coordination Meetings and Briefings	

Tuesday, December 21

Weather Conditions (Daylight)	Air: Low-to-medium low visibility. Overcast. High west winds at 25 knots.
Argo Merchant	0800: Bearing 258°. Pitching up to 10 feet. 100° behind bridge. 0835: Ship split in two aft of king post. Approximately 1½ million gallons of oil released after breakup. Bow bearing 025°, stern 260°.
USCG Operations	Bow bearing 045°. Grinding on stern. USCGC *Vigilant* on scene entire day.
Overflights	0930: HU-16E. Mapping. 1245: H-3. Inspection of vessel.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E; mapped breakup dump. Personnel aboard WHOI *Oceanus*. " " H-3.
Other Operations	
Ship Cruises	1438: WHOI *Oceanus* cruise ends because of severe weather. USGS *Whitefoot* cruise begins.
Spill Characteristics	Heavy slick extending east 6 miles, averaging 2½ miles in width. Sheen extending 8 miles east from mixed heavy "pancakes." Area of dispersed "pancakes" extending 60 miles east and 25 miles north.
Coordination Meetings and Briefings	

Wednesday, December 22

Weather Conditions (Daylight)	Air: High visibility. Broken clouds. High west winds at 50 to 15 knots. Sea: Fifteen- to 5-foot waves.
Argo Merchant	0730: Bow section splits forward of bridge. Ship in three pieces. Ice 1/4 inch thick. Center section sunk, bearing 45°.
USCG Operations	1930: USCGC *Bittersweet* arrives on scene. USCGC *Vigilant* on scene entire day.
Overflights	1005: HU-16E. Mapping. Whale sighted. 1044: H-3. Differential velocity measurements. Oil samples. 1130: NASA C-54. 1505: PA-23. Oblique and vertical photos. NASA Landsat. EPA oil survey.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E and H-3.
Other Operations	AMSI conducts overflights.
Ship Cruises	NOAA/NMFS *Delaware II* cruise DE76-13. Begins measurement of environmental conditions, XBT temperature profiles, surface and column water samples, fish and bottom biological samples for two stations. Plankton, neuston, and bottom sediment samples at six stations. Bird fouling noted. USGS *Whitefoot* cruise. USCG *Evergreen* cruise begins.
Spill Characteristics	Three mixed patches of densely packed "pancakes" interspersed among large patches of lightly packed "pancakes" extending 100 miles east and averaging 25 miles in width.
Coordination Meetings and Briefings	1000-1130: EPA scientific meeting in Boston. 1900-1930: Senator Edward Kennedy's public hearing.

Thursday, December 23

Weather Conditions (Daylight)	Air: Medium visibility. Scattered clouds. Medium northwest winds at 20 knots. Sea: Calm. Small waves. Two- to 3-foot swells.
Argo Merchant	Unchanged.
USCG Operations	1250: Strike force boards *Argo Merchant* and opens hatches. 1616: Strike force departs. USCGC's *Vigilant* and *Bittersweet* on scene entire day.
Overflights	0855: H-3. 1035: HU-16E. Mapping. Current measurements. Whale sighted. 1140: PA-23. Current probes. Photos. Two whales sighted. 1257: H-3. NASA Landsat.
NOAA/USCG SOR Team Operations	Personnel aboard both HU-3 overflights, as well as aboard HU-16E.
Other Operations	0855-1140: Navy divers dive below slick and complete bottom survey. AMSI overflight.
Ship Cruises	NOAA/NMFS *Delaware II* cruise continues. USGS *Whitefoot* cruise. USCG *Evergreen* cruise.
Spill Characteristics	Total extent 90 miles with average width of 30 miles. Heavy "pancake" concentrations extending 25 miles east of *Argo Merchant*. Light "pancake" concentrations further out surrounded by sheen.
Coordination Meetings and Briefings	

Friday, December 24

Weather Conditions (Daylight)	Air: Medium visibility. Scattered clouds. Medium northwest winds at 20 knots. Sea: Calm.
Argo Merchant	Unchanged. Stern bearing 260°, bow 45°.
USCG Operations	USCGC's *Vigilant* and *Bittersweet* on scene entire day.
Overflights	0945: HU-16E. Mapping. 0958: PA-23. Surface markers. 1014: H-3.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E and H-3.
Other Operations	AMSI overflight.
Ship Cruises	NOAA/NMFS *Delaware II* cruise completed. USGS *Whitefoot* cruise ends. USCG *Evergreen* cruise.
Spill Characteristics	Total extent 100 miles east. Two flukes formed at the end, with a width of 10 to 20 miles. Moderate concentration of "pancakes" along center, surrounded by light concentrations.
Coordination Meetings and Briefings	

Saturday, December 25

Weather Conditions (Daylight)	Air: Medium visibility. Cloud base approximately 1000 feet. Medium southwest winds at 20 knots. Sea: Calm.
Argo Merchant	Unchanged.
USCG Operations	Forecast of onshore wind conditions. Reactivation of personnel. Beach cleanup contingency. USCGC's *Bittersweet* and *Vigilant* on scene entire day.
Overflights	1018: HU-16E. Mapping of "Pancake 1." *Vigilant* directed to "pancake" for sampling.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E.
Other Operations	
Ship Cruises	USCGC *Evergreen* cruise.
Spill Characteristics	Plume tracked out to 80 miles east, averaging 20 to 30 miles in width. "Pancake 1" spotted 35 miles east of *Argo Merchant*.
Coordination Meetings and Briefings	

Sunday, December 26

Weather Conditions (Daylight)	Air: Medium-to-low visibility. Overcast. Rain, fog, and snow. Medium-to-high southeast winds at 15 knots, veering toward northwest at 35 knots. Sea: Two- to 3-foot waves.
Argo Merchant	Unchanged.
USCG Operations	1345: Four drops of drift cards. USCGC's *Bitterwweet* and *Vigilant* on scene entire day.
Overflights	0916: HU-16E. Mapping of "Pancake 1." Oil current and drift cards dropped.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16E. Dropped 3180 drift cards.
Other Operations	
Ship Cruises	USCGC *Evergreen* cruise.
Spill Characteristics	Plume tracked 40 miles east, averaging 40 miles in width. "Pancake 1" 40 miles east. Marked with drift cards.
Coordination Meetings and Briefings	

Monday, December 27

Weather Conditions (Daylight)	Air: Medium visibility. Low cloud base. High west winds at 33 knots. Sea: Eight-foot waves.
Argo Merchant	0800: Bow section rolled over.
USCG Operations	USCGC's *Bittersweet* and *Vigilant* on scene entire day. A total of 3000 drift cards dropped on three separate occasions. 1600: First burning experiment completed.
Overflights	0900: H-3. 0912: HU-16E. Mapping. Dropped data marker buoy. 1324: PA-23. Drift cards dropped.
NOAA/USCG SOR Team Operations	Personnel aboard H-3 and HU-16 flights.
Other Operations	AMSI overflight.
Ship Cruises	WHOI *Oceanus* cruise 20. Collection of suspended sediment samples and bottom sediment. USGS *Whitefoot* cruise. USCGC *Evergreen* cruise.
Spill Characteristics	Plume seen as one large butterfly-shaped patch 110 miles long and 10 to 40 miles wide, with furthest edge 140 miles. Smaller patch 20 miles long and 5 miles wide.
Coordination Meetings and Briefings	

Tuesday, December 28

Weather Conditions (Daylight)	Air: Very low visibility. No visibility at 1000 feet. Overcast. Medium west winds veering toward east at 15 knots. Sea: Data ship into lee.
Argo Merchant	Unchanged.
USCG Operations	1528: USCGC *Bittersweet* relieves USCGC *Vigilant*. *Vigilant* departs. *Bittersweet* remains on scene.
Overflights	No flights because of poor weather.
NOAA/USCG SOR Team Operations	Assisted in OSC press conference.
Ship Cruises	WHOI *Oceanus* cruise 20 continues. URI *Endeavor* cruise begins. USGS *Whitefoot*. Plankton tows. Water and sediment samples. USCGC *Evergreen* cruise ends.
Spill Characteristics	No determination because of weather preventing overflights.
Coordination Meetings and Briefings	OSC press conference. SOR Team and USCG representatives meet with Marine Mammals Commission in Boston.

Wednesday, December 29

Weather Conditions (Daylight)	Air: Low-to-medium visibility. Overcast. Rain. Medium-high east winds at 20 knots, veering toward west at 35 knots. Sea: Three- to 4-foot waves. Five- to 6-foot swells.
Argo Merchant	Bow section moving slightly to southeast.
USCG Operations	USCGC *Bittersweet* on scene entire day.
Overflights	No flights because of poor weather.
NOAA/USCG SOR Team Operations	
Other Operations	
Ship Cruises	WHOI *Oceanus* cruise 20 ends. URI *Endeavor* cruise ends.
Spill Characteristics	No determination because of weather preventing overflights.
Coordination Meetings and Briefings	

Thursday, December 30

Weather Conditions (Daylight)	Air: Medium visibility. Broken clouds. Snow. High west winds at 40 knots. Sea: Four- to 6-foot waves. Twelve- to 16-foot swells.
Argo Merchant	Bow section moved 400-500 yds southeast of stern. Bow capsized. Bearing 130°.
USCG Operations	A total of 2000 drift cards dropped at two locations. USCGC's *Spar* arrives on scene. USCGC's *Bittersweet* and *Dallas* on scene.
Overflights	1002: PA-23. Drift cards and dye markers. H-3. Drift cards.
NOAA/USCG SOR Team Operations	Personnel aboard H-3.
Other Operations	AMSI overflight.
Ship Cruises	URI *Endeavor*. USCGC *Dallas*.
Spill Characteristics	No determination because of poor weather.
Coordination Meetings and Briefings	

Friday, December 31

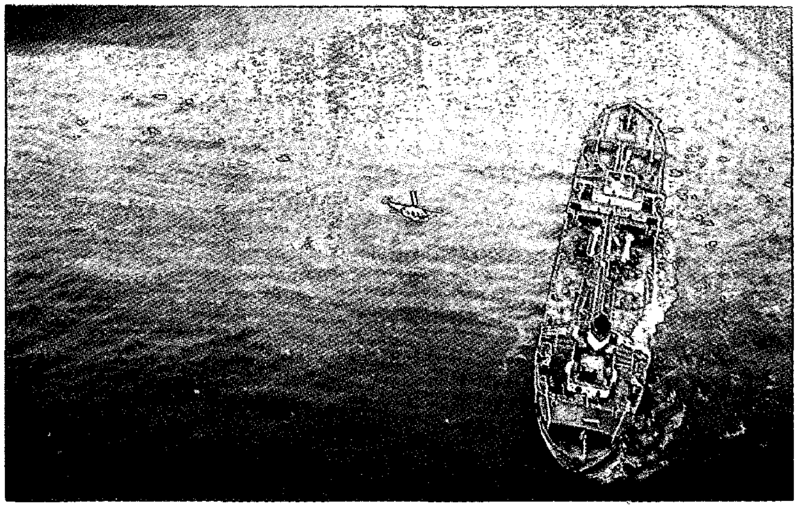
Weather Conditions (Daylight)	Air: Low-to-medium visibility. Snow. Medium west winds at 15 knots. Sea: Two-foot waves. Three- to 6-foot swells.
Argo Merchant	Bow, bearing 140°, holed with 20-mm cannon fire to prevent drifting and remove navigation hazard.
USCG Operations	USCGC *Spar*. Burning experiment. Sample of slick obtained.
Overflights	1254: PA-23. Drift cards and dye markers. 1530: H-3. Buoy deployed on "pancake." HU-16E mapping. AMSI overflight.
NOAA/USCG SOR Team Operations	Personnel aboard HU-16 and H-3. Begin whale watching.
Other Operations	
Ship Cruises	USCGC *Spar*.
Spill Characteristics	Leading edge further than 140 miles out from *Argo Merchant* location in general southeast direction.
Coordination Meetings and Briefings	1000: Secretary of Transportation press conference.

APPENDIX III

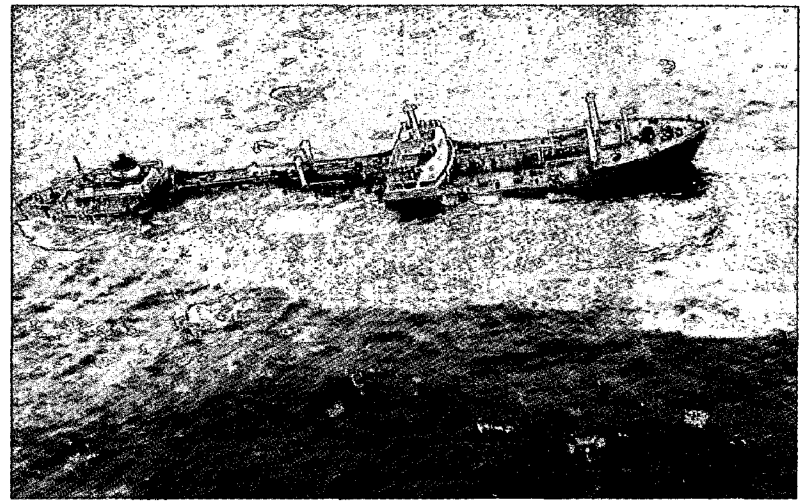
Selected Photographs

List of Photographs

No.	Description	Credit
1.	Argo Merchant, Dec. 16, 1976	SOR
2.	Argo Merchant, Dec. 17, 1976	SOR
3.	Argo Merchant, Dec. 18, 1976	SOR
4.	Argo Merchant, Dec. 19, 1976	SOR
5.	Argo Merchant, Dec. 20, 1976	SOR
6.	Argo Merchant, Dec. 21, 1976	SOR
7.	Argo Merchant, after first break, Dec. 22, 1976	SOR
8.	Argo Merchant, after second break, Dec. 24, 1976	SOR
9.	Argo Merchant, Dec. 25, 1976	SOR
10.	Argo Merchant, Dec. 27, 1976	SOR
11.	Argo Merchant, Dec. 31, 1976	SOR
12.	Argo Merchant, stern section, Jan. 2, 1977	SOR
13.	Argo Merchant, stern section, Jan. 3, 1977	SOR
14.	Argo Merchant, bow section, Jan. 3, 1977	SOR
15.	Argo Merchant, bow section, Jan. 4, 1977	SOR
16.	Argo Merchant, bow section, Jan. 5, 1977	SOR
17.	Oil slick, Dec. 19, 1976 (frame 0037)	NASA
18.	Oil slick, Dec. 19, 1976 (frame 0108)	NASA
19.	Oil slick, Dec. 19, 1976, at 1023 (frame 0149)	NASA
20.	Oil slick, Dec. 19, 1976, at 1037 (frame 0061)	NASA
21.	End of slick, Dec. 19, 1976 (frame 0091)	NASA
22.	Photomosaic of oil slick, Dec. 19, 1976	NASA
23.	Composite mosaic of oil slick, Dec. 19, 1976	NASA
24.	Oil slick, Dec. 22, 1976 (frame 0260)	NASA
25.	Oil slick, Dec. 22, 1976 (frame 0279)	NASA
26.	Oil slick, Dec. 22, 1976 (frame 0318)	NASA
27.	Oil slick, Dec. 22, 1976 (frame 0321)	NASA
28.	Oil slick, Dec. 22, 1976 (frame 0336)	NASA
29.	Underside of pancake	USN
30.	Edge of pancake	USN
31.	Divers' dye experiment	SOR
32.	Waves being absorbed by oil (lower right)	SOR
33.	Richardson current probe and smoke	SOR
34.	Richardson current probe and smoke	SOR
35.	Setup for differential velocity measurement	SOR
36.	Same as photograph 33, but 20.4 seconds later	SOR
37.	Pancake 1, Dec. 25, 1976	SOR
38.	Pancake 1, Dec. 25, 1976, 3 hours later	SOR
39.	Pancake, 8 x 12 feet, Dec. 19, 1976	SOR
40.	Pancake, 8 x 10 feet, Dec. 22, 1976	SOR
41.	Pancake, 10 x 20 feet	SOR
42.	Pancake, 300 feet, before burn test, Dec. 27, 1976	SOR
43.	Burn test on 300-foot pancake, Dec. 27, 1976	SOR
44.	Burn test on 200-foot pancake, Dec. 31, 1976	SOR
45.	Oil sample from 2 inch thick oil slick	SOR
46.	Failed attempt to sample sheen and thin oil	SOR
47.	Oiled Herring Gull	SOR
48.	Finback whale sighted on Jan. 6, 1977	SOR



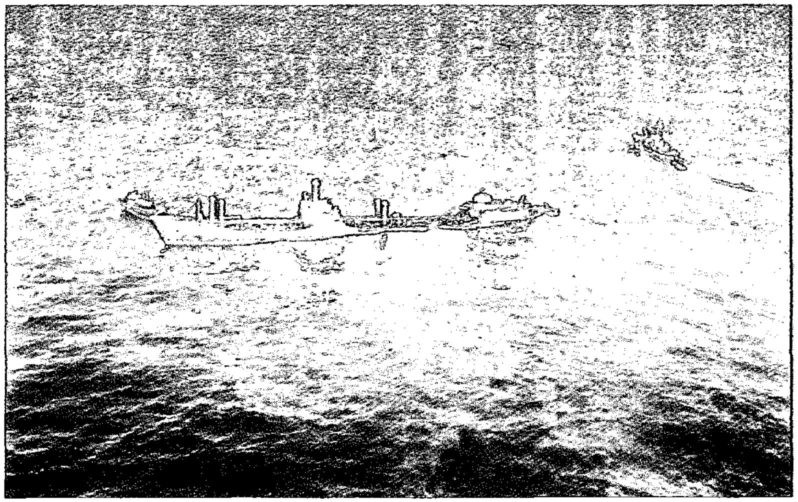
1. Argo Merchant, *Dec. 16, 1976.*



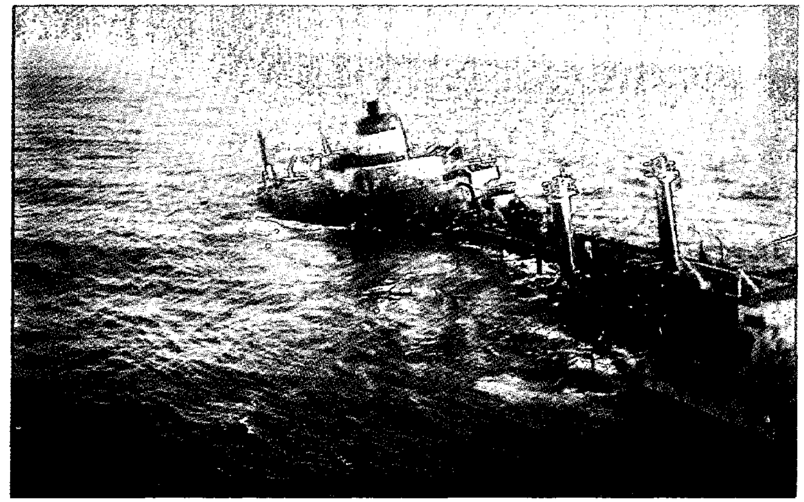
2. Argo Merchant, *Dec. 17, 1976.*

3. Argo Merchant, *Dec. 18, 1976.*

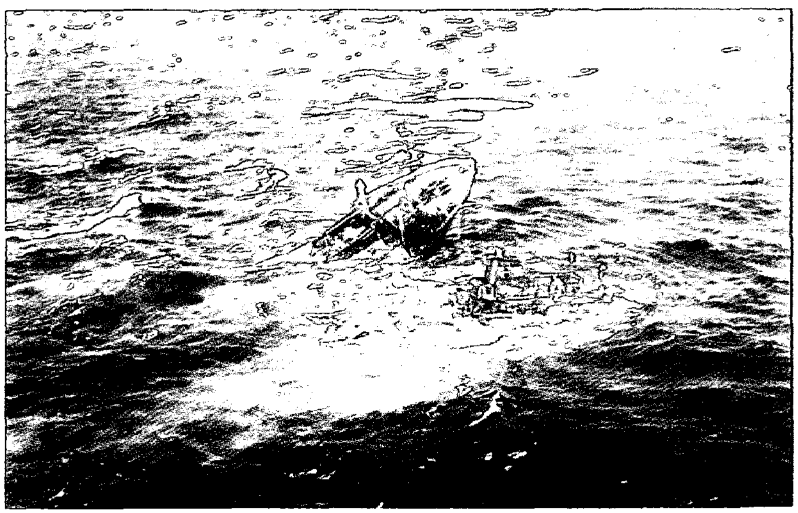
4. Argo Merchant, *Dec. 19, 1976.*



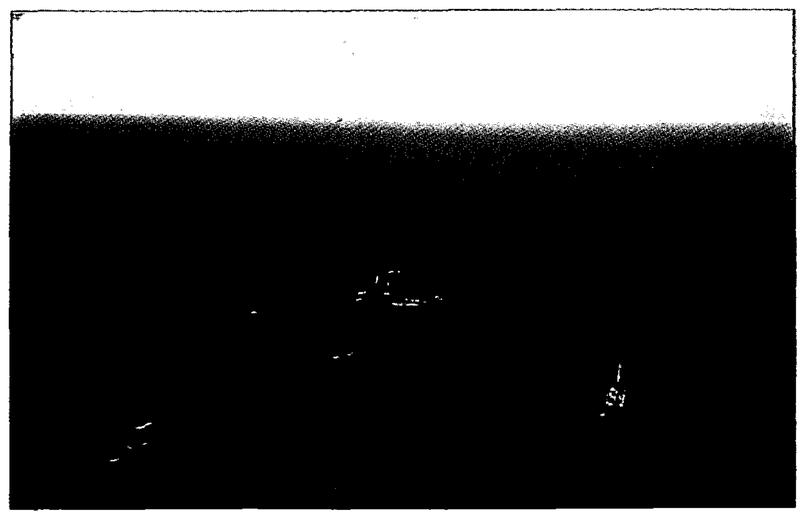
5. Argo Merchant, *Dec. 20, 1976.*



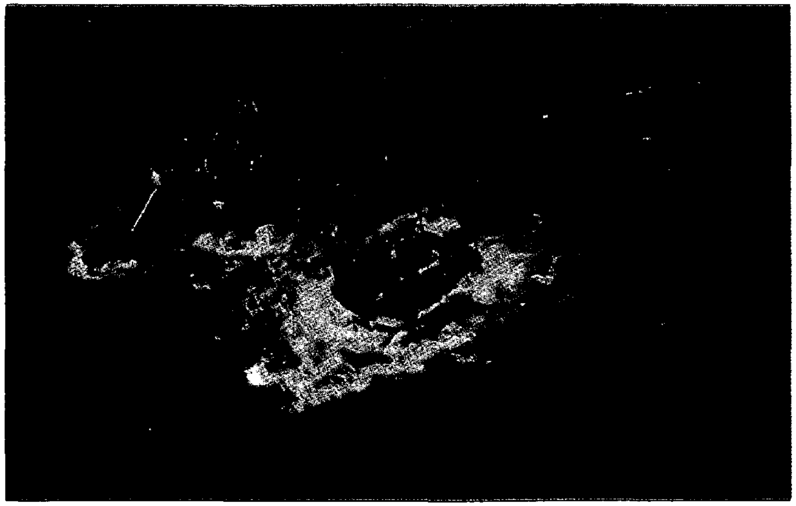
6. Argo Merchant, *Dec. 21, 1976.*



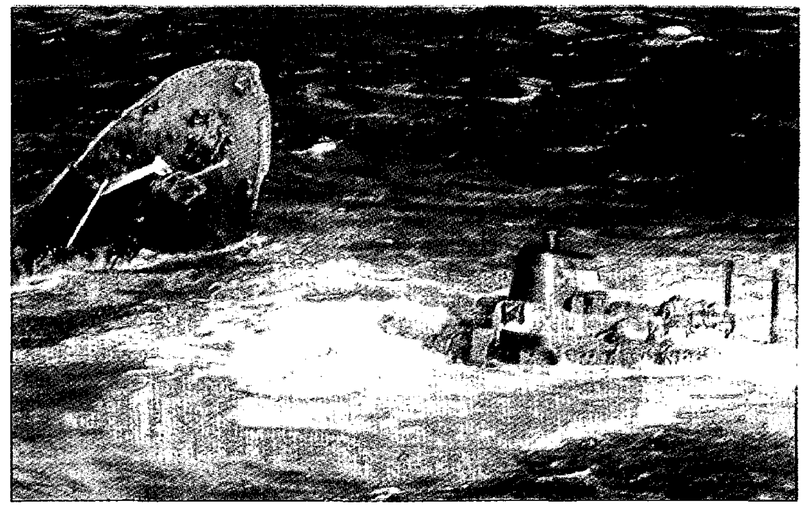
7. Argo Merchant, *after first break, Dec. 22.*



8. Argo Merchant, *after second break, Dec. 24.*



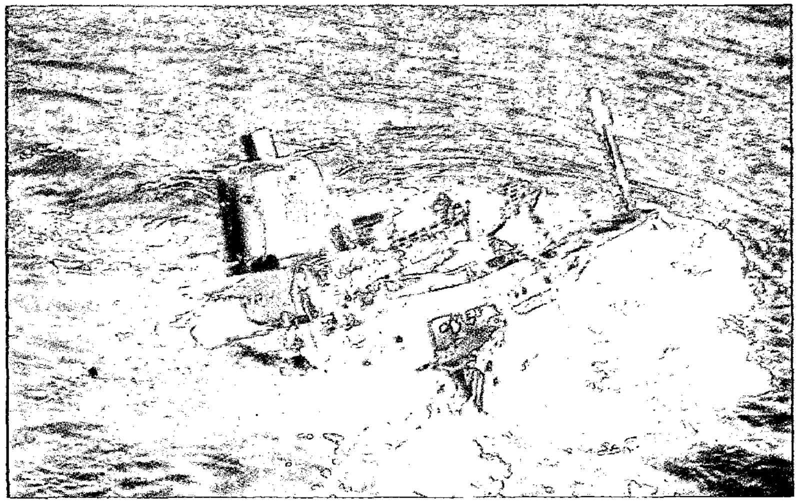
9. Argo Merchant, *Dec. 25.*



10. Argo Merchant, *Dec. 27.*

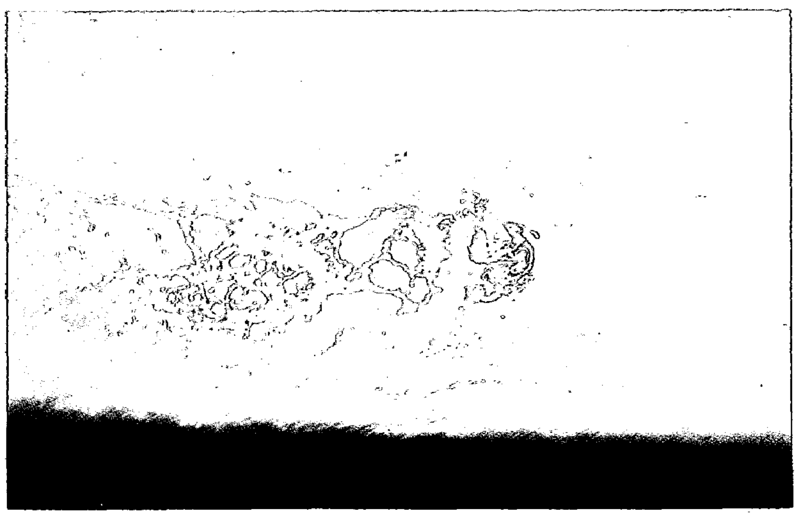
11. Argo Merchant, *Dec. 31.*

12. Argo Merchant, *stern section, Jan. 2.*

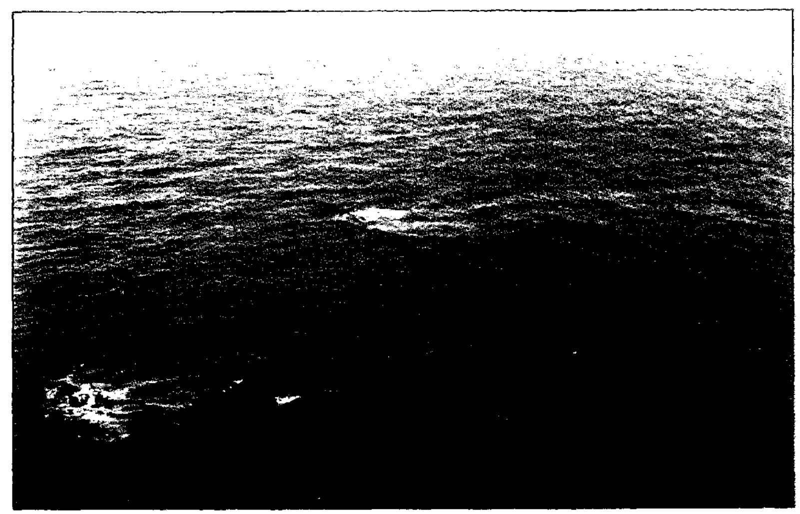


13. Argo Merchant, *stern section, Jan. 3.*

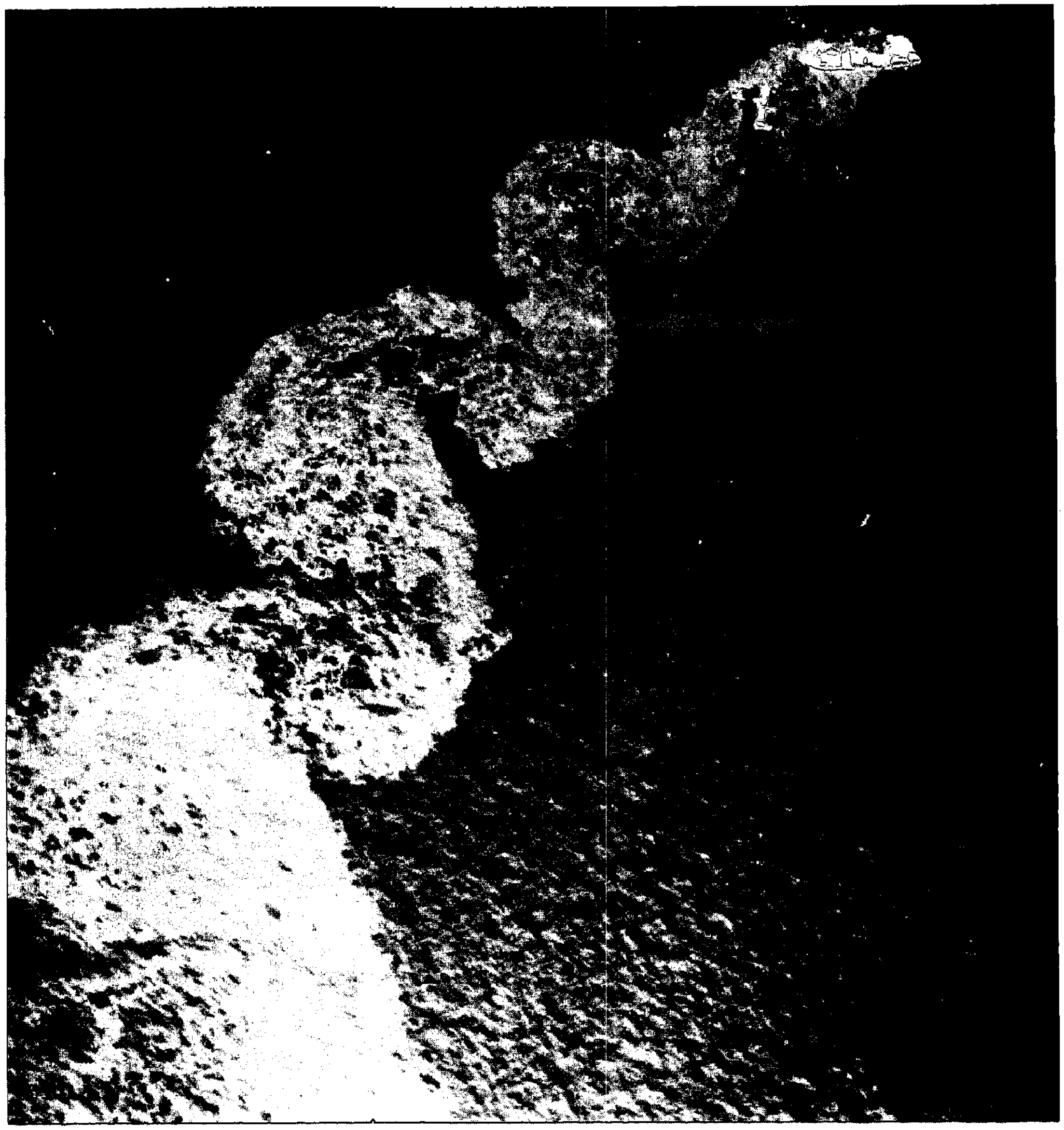
14. Argo Merchant, *bow section, Jan. 3.*



15. Argo Merchant, *bow section, Jan. 4.*



16. Argo Merchant, *bow section, Jan. 5.*

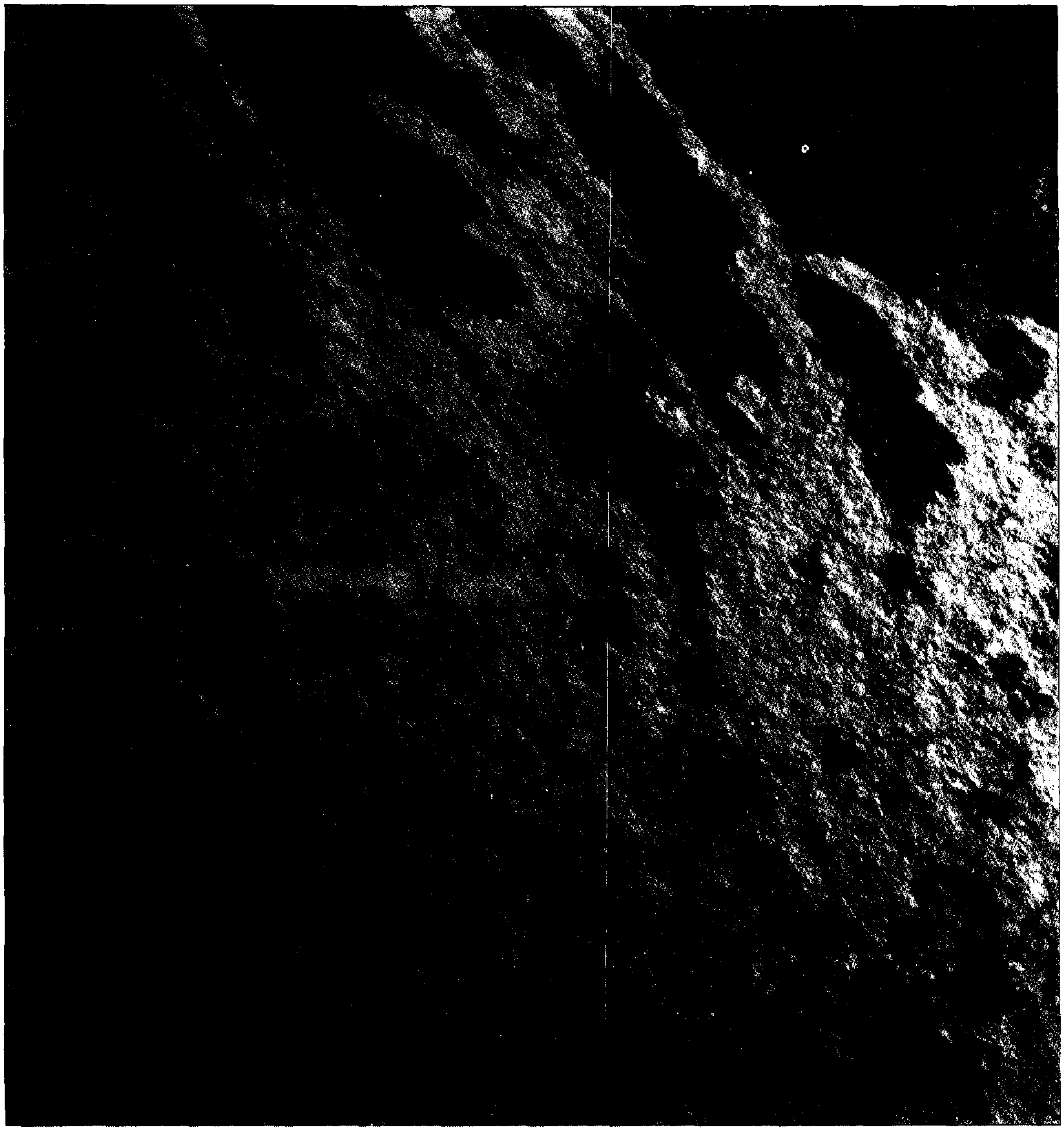


17. Oil slick, Dec. 19.

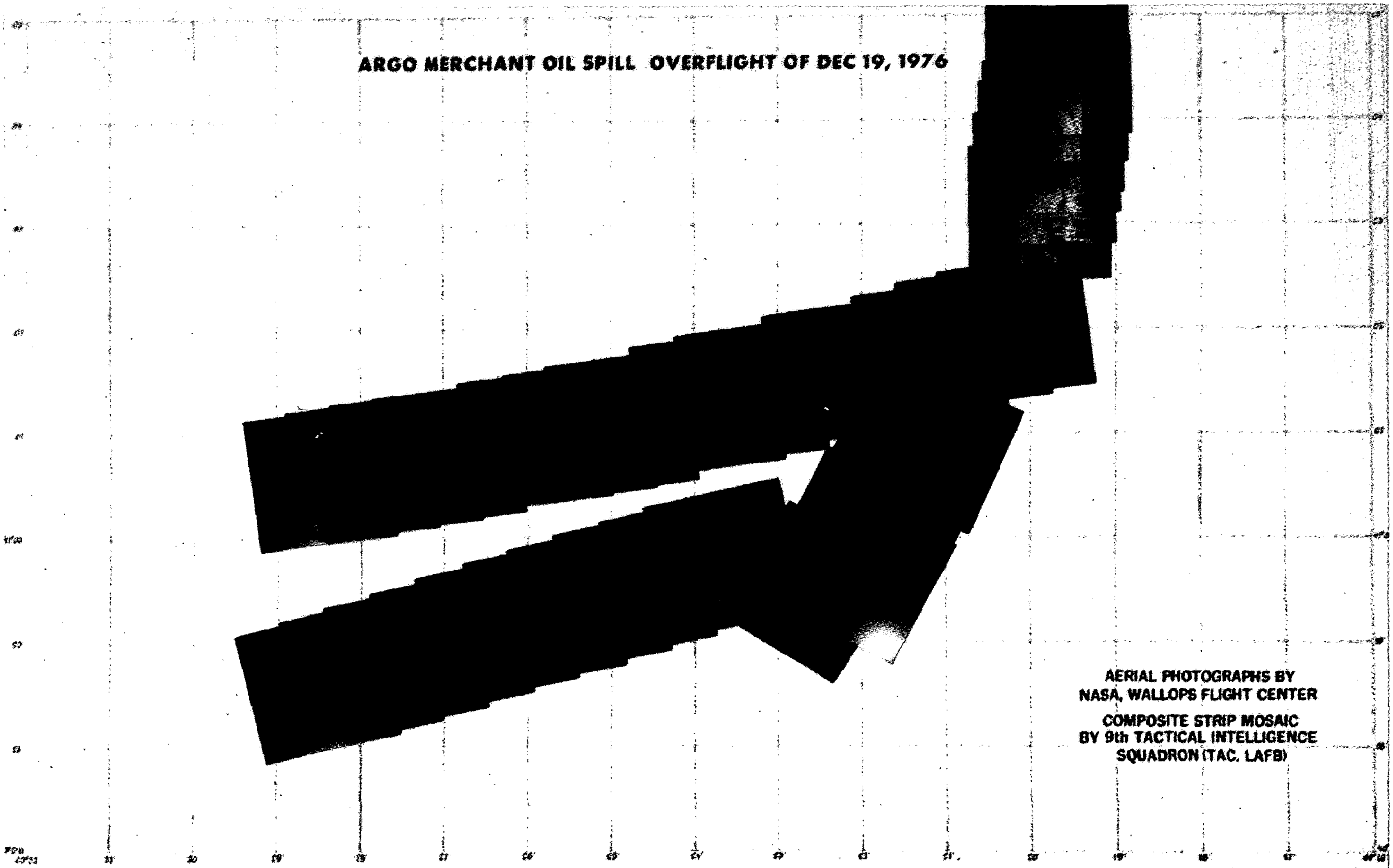
18. Oil slick, Dec. 19.

19. Oil slick, Dec. 19 at 1023.

20. *Oil slick, Dec. 19 at 1037.*

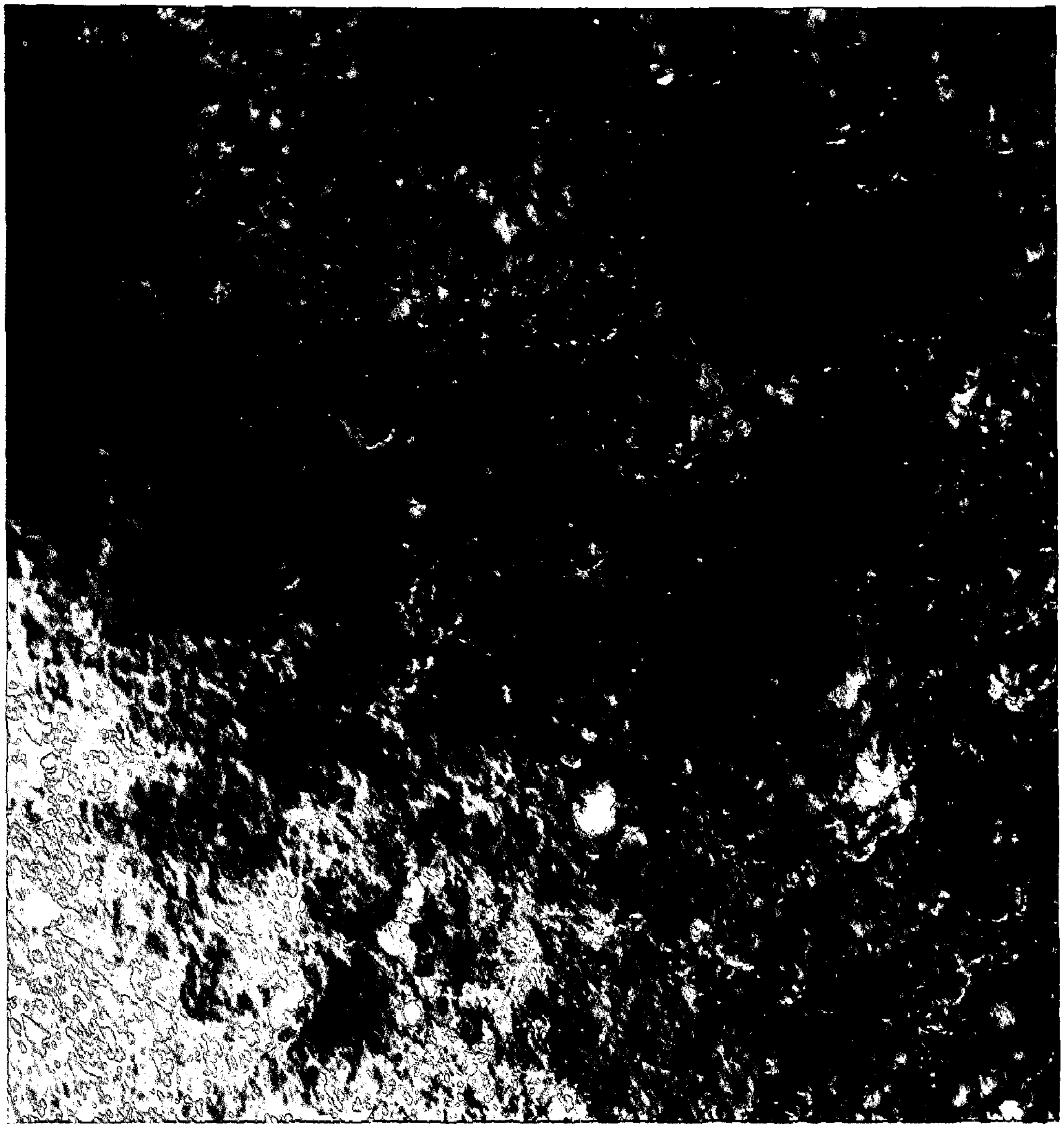


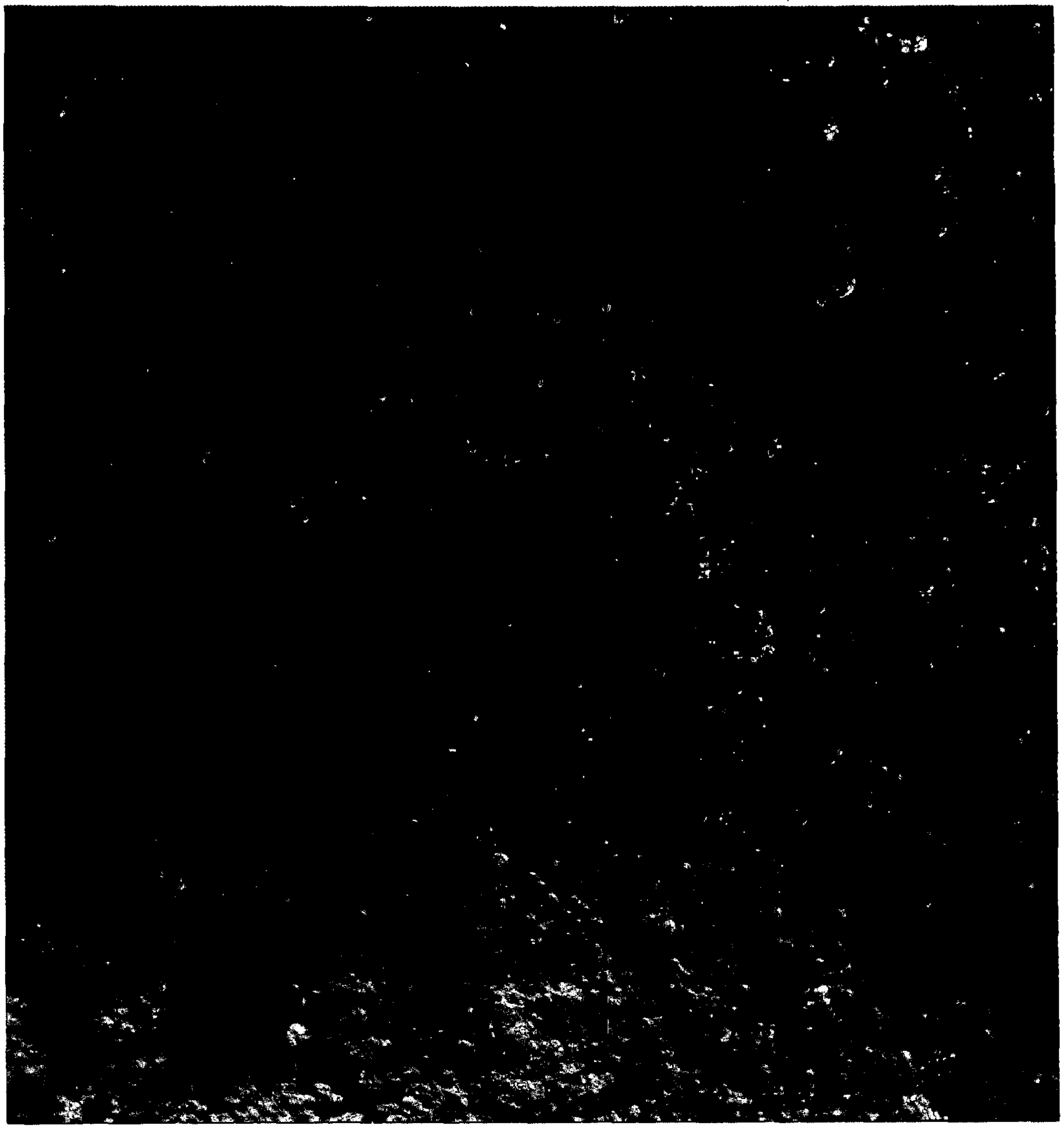
21. *End of slick, Dec. 19.*



22. *Photomosaic of oil slick, Dec. 19.*

23. *Composite mosaic of oil slick, Dec. 19.*

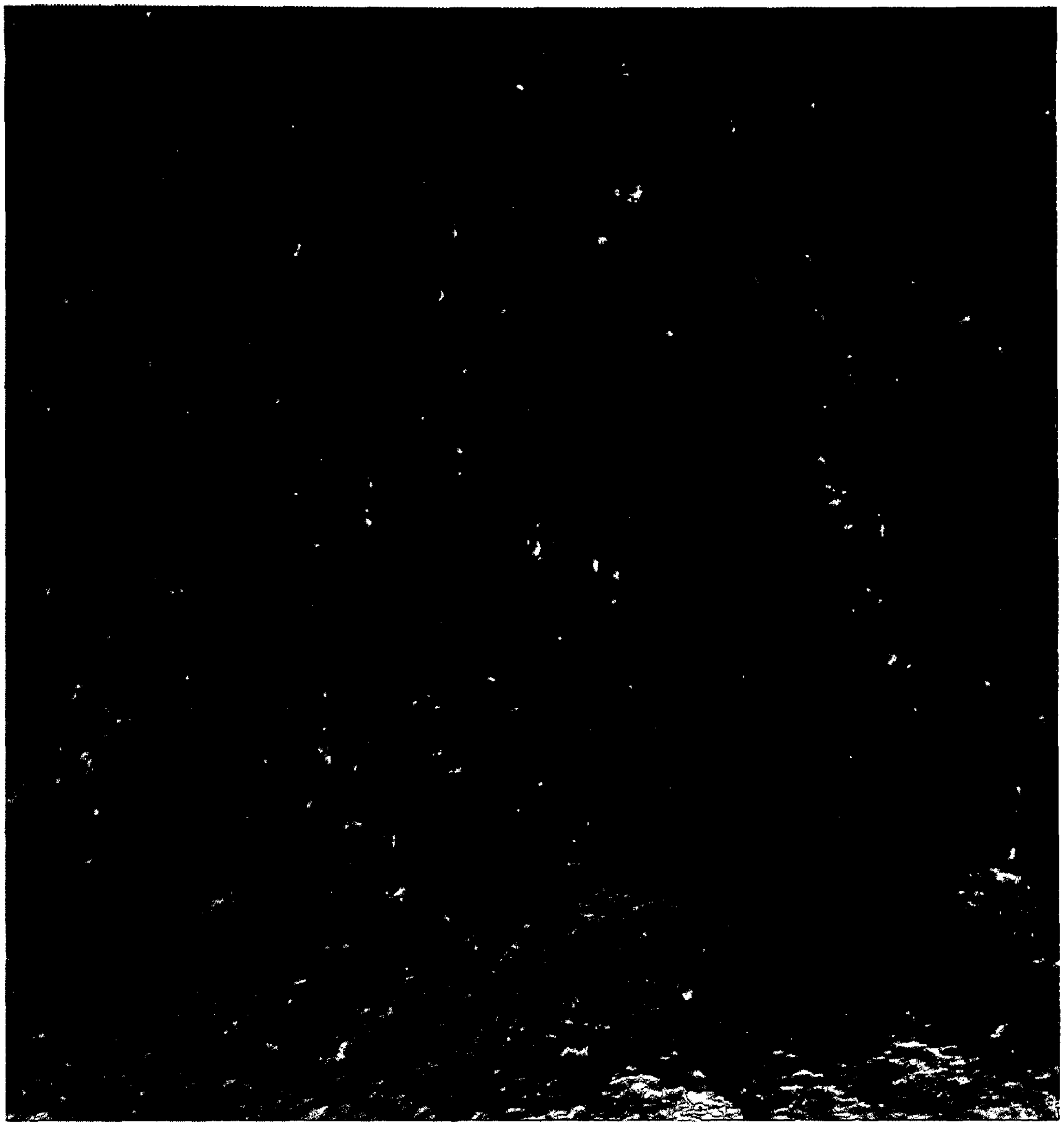

24. Oil slick, Dec. 22.



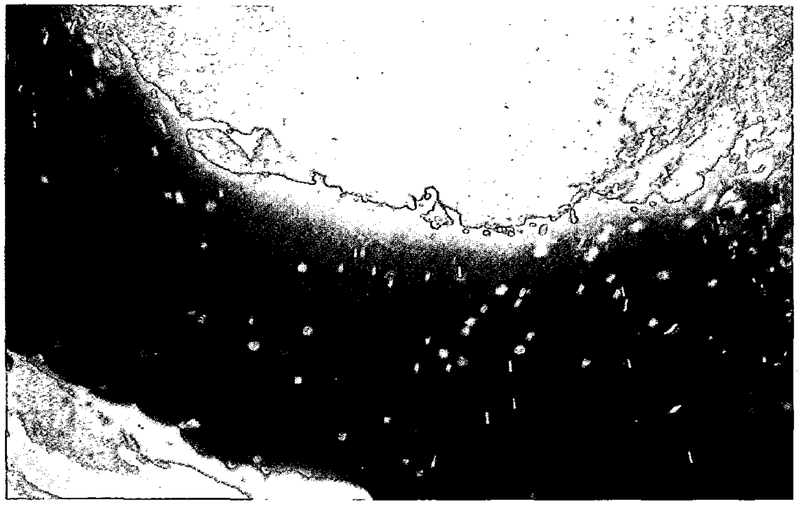
25. *Oil slick, Dec. 22.*

26. Oil slick, Dec. 22.

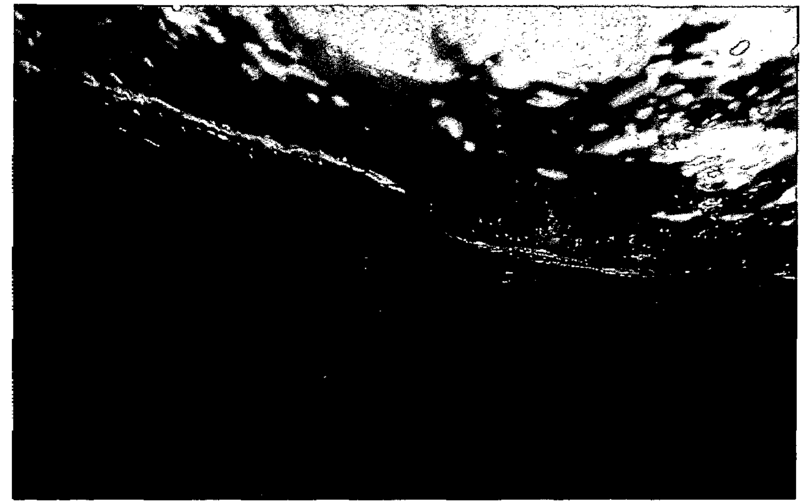
27. Oil slick, Dec. 22.



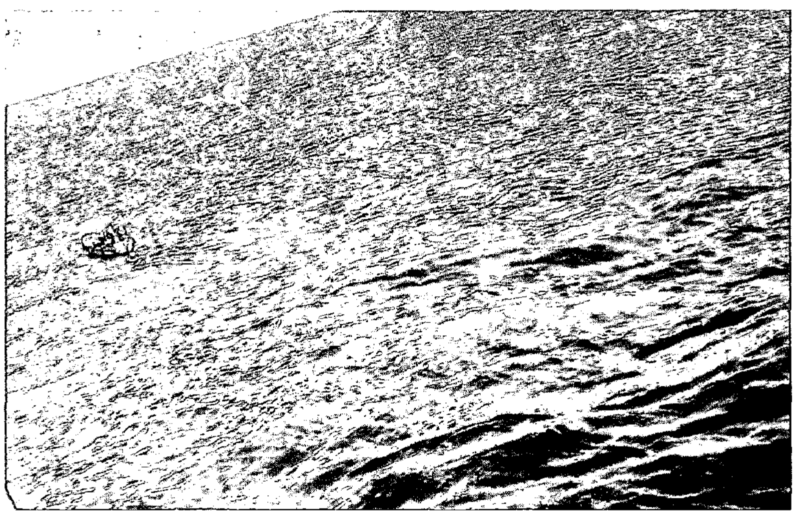
28. *Oil slick, Dec. 22.*



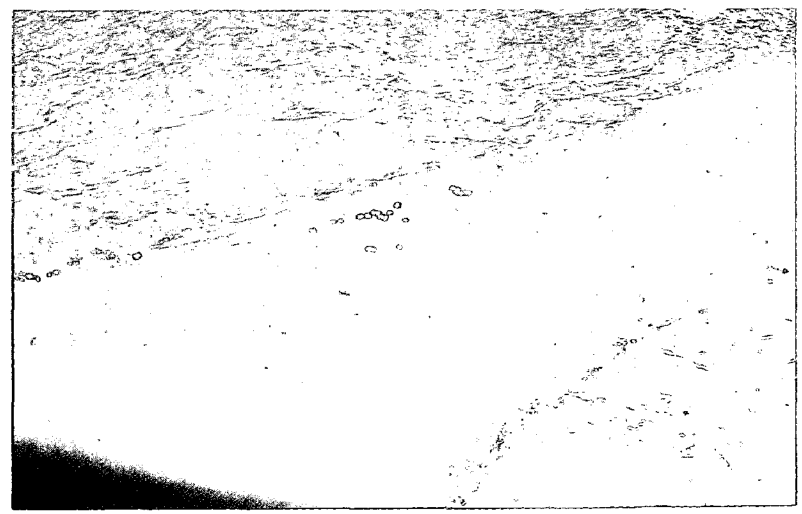
29. *Underside of oil pancake.*



30. *Edge of oil pancake.*

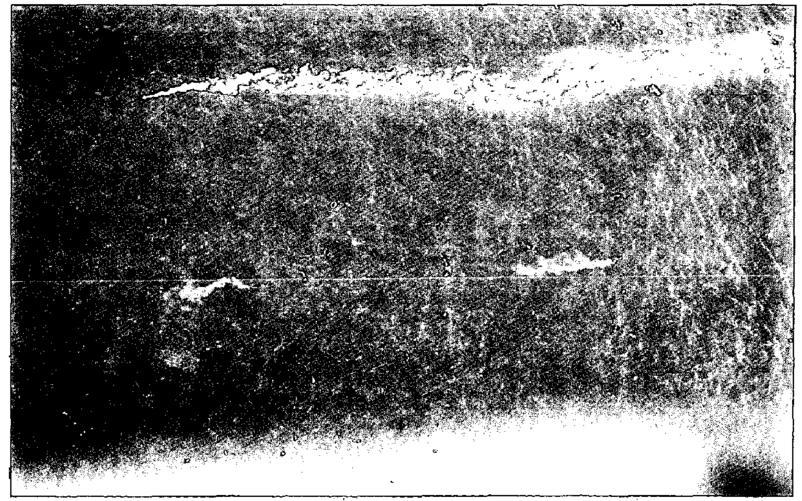


31. *Divers' dye experiment.*

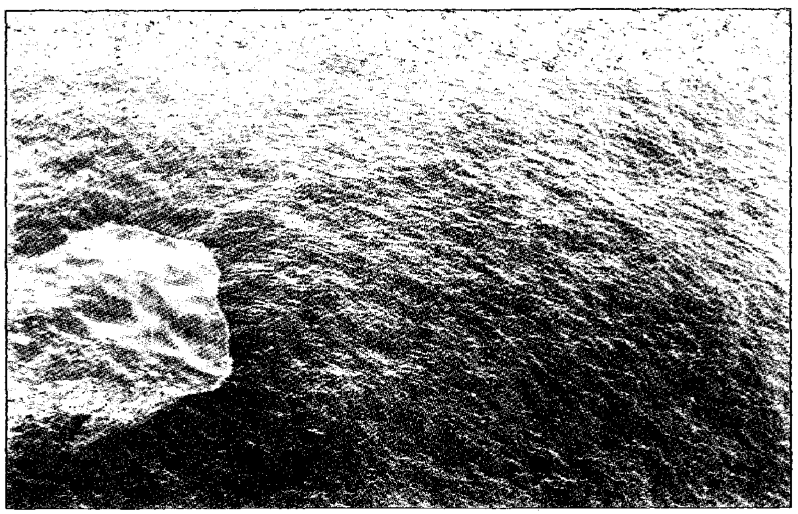


32. *Waves being absorbed by oil (lower right).*

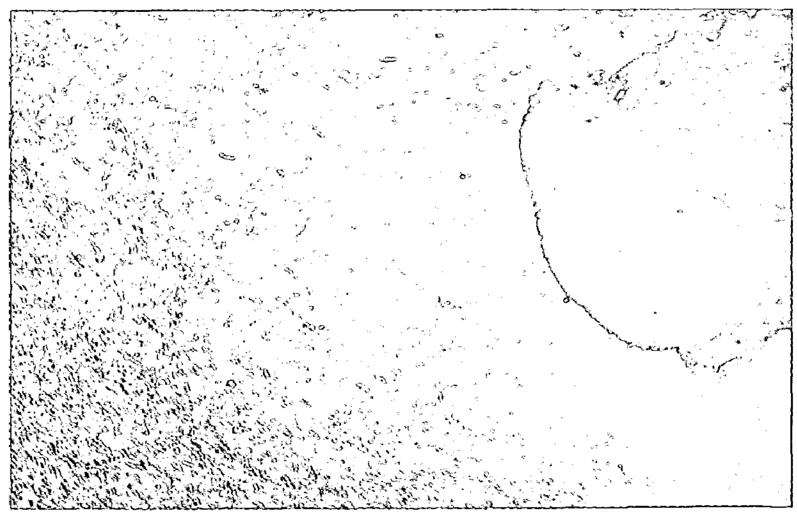
33. *Richardson current probe and smoke.*



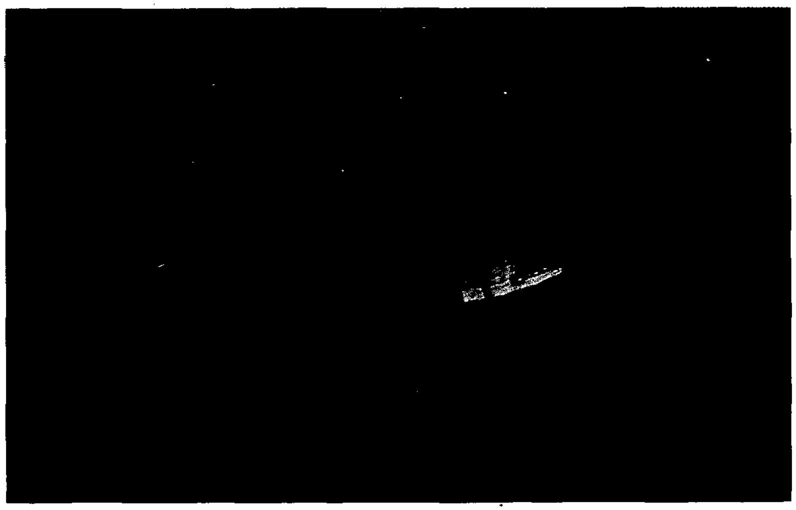
34. *Richardson current probe and smoke.*



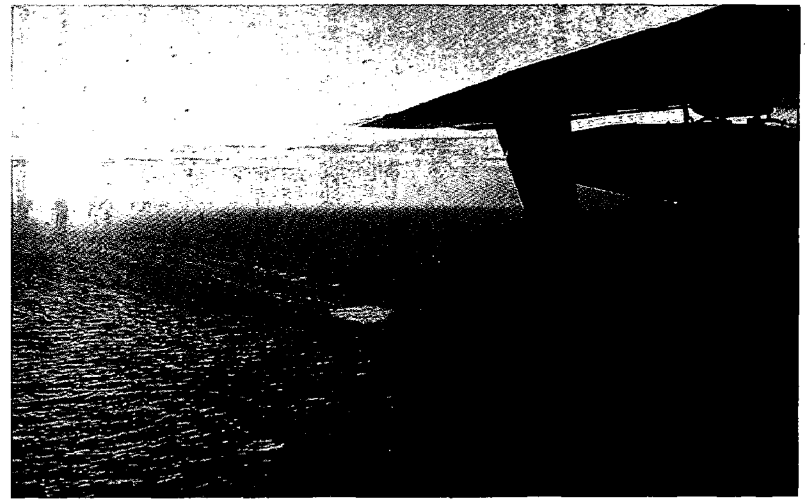
35. *Setup for differential velocity measurement.*



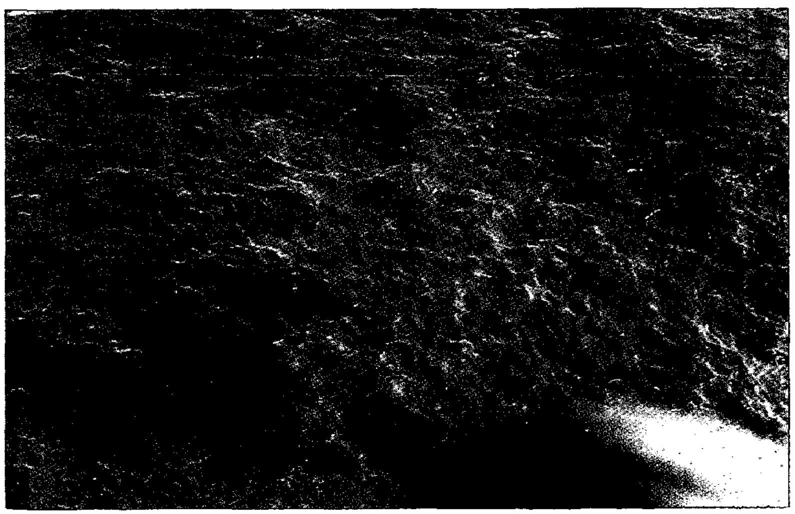
36. *Same as 33, but 20.4 seconds later.*



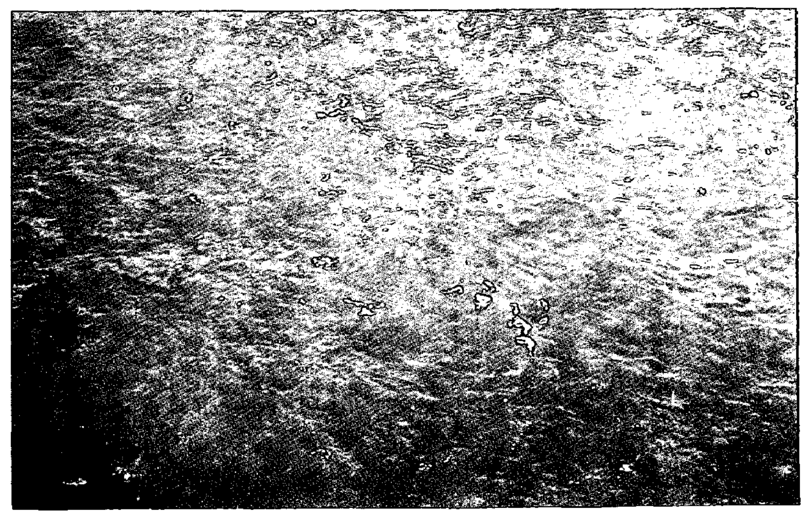
37. *Pancake 1, Dec. 25.*



38. *Pancake 1, Dec. 25, 3 hr later.*

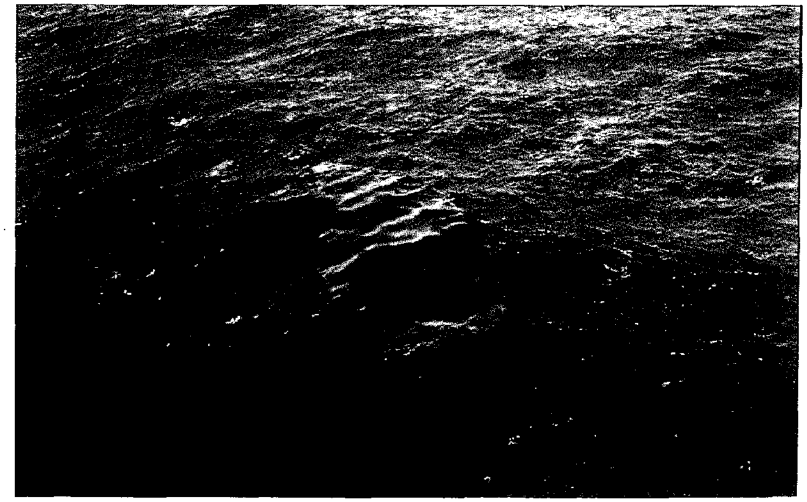


39. *Pancakes, 8 x 12 ft, Dec. 19.*



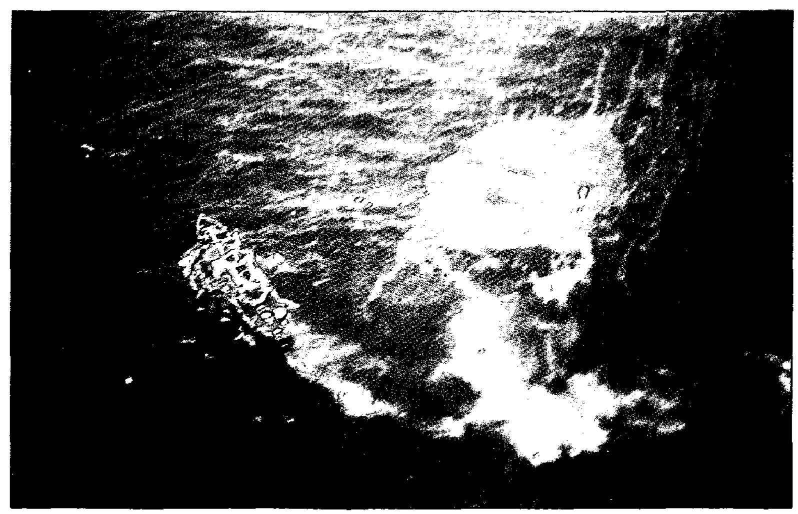
40. *Pancakes, 8 x 10 ft, Dec. 22.*

41. Pancake, 10 x 20 ft.



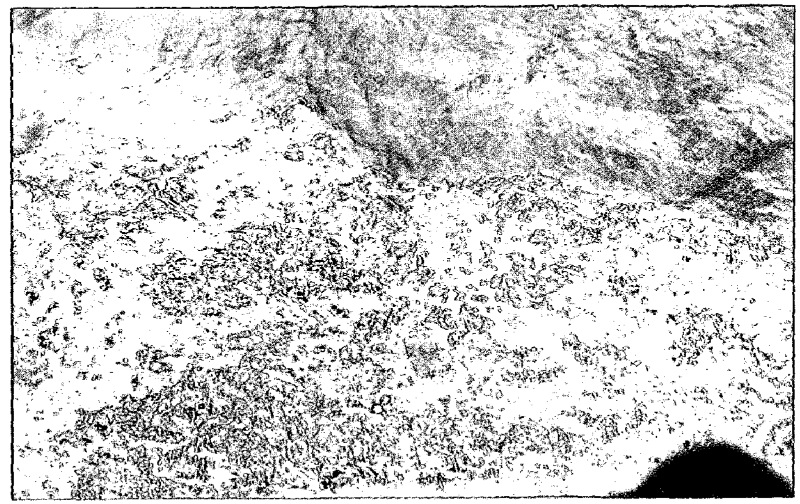
42. Pancake, 300 ft, before burn test, Dec. 27.

43. Burn test on 300-ft pancake, Dec. 27.

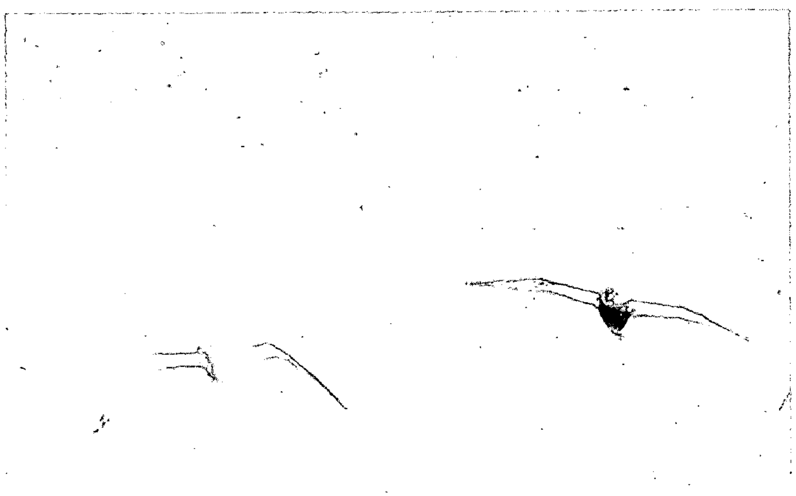


44. Burn test on 200-ft pancake, Dec. 31.

45. Oil sample from 2 in. thick oil slick.



46. Failed attempt to sample sheen and thin oil.



47. Oiled Herring Gull.

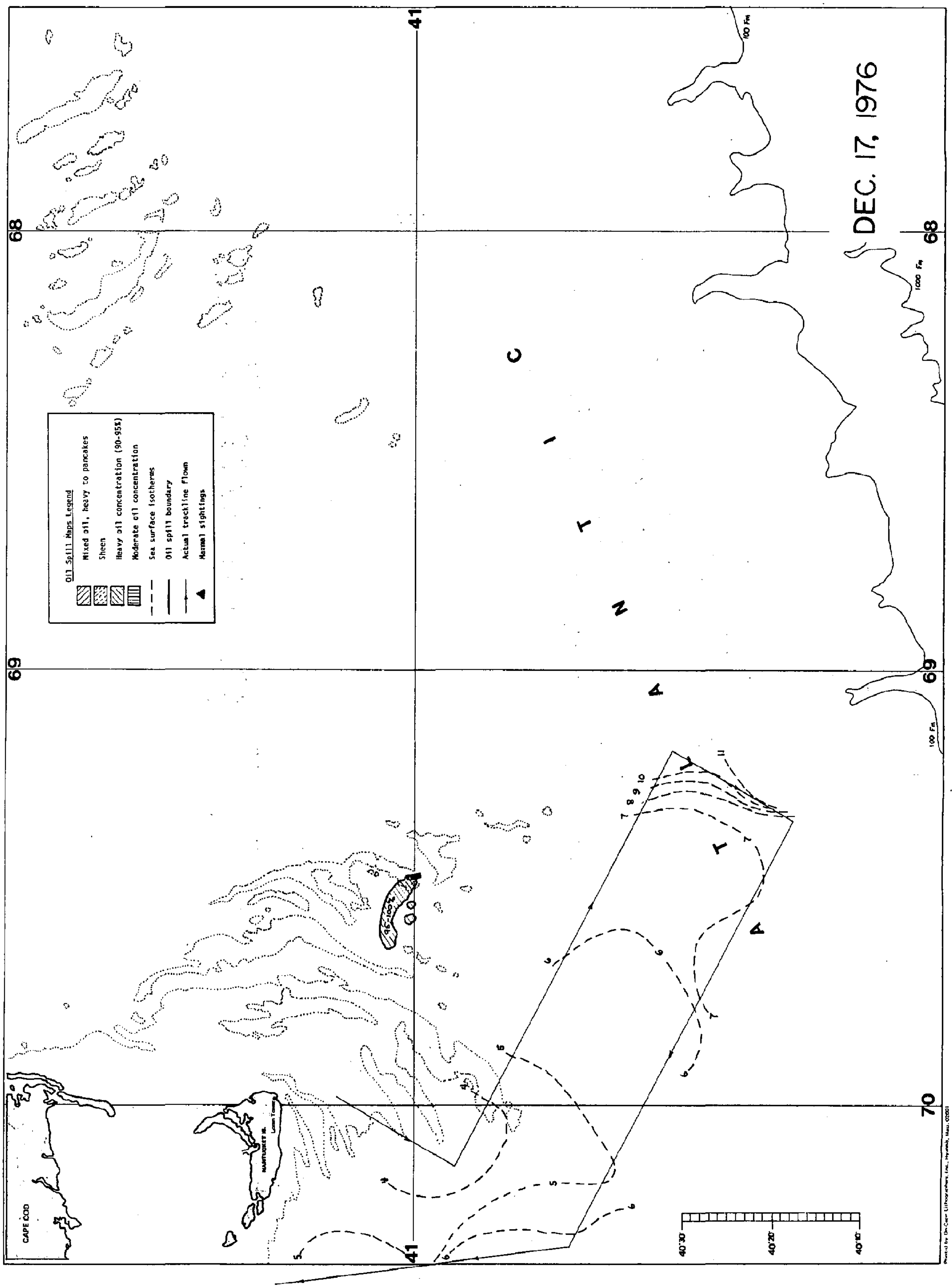
48. Finback whale sighted on Jan. 6.

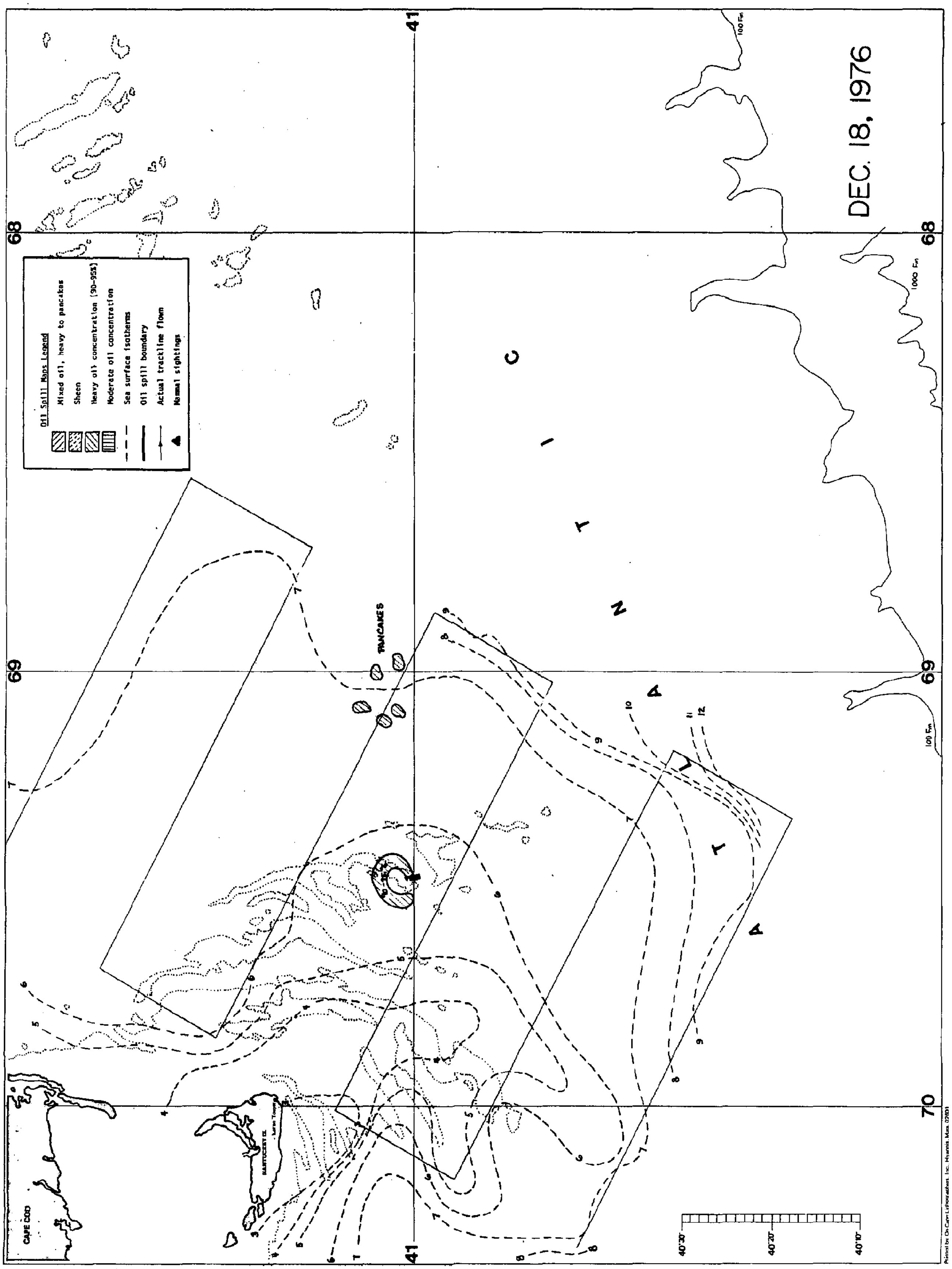
APPENDIX IV

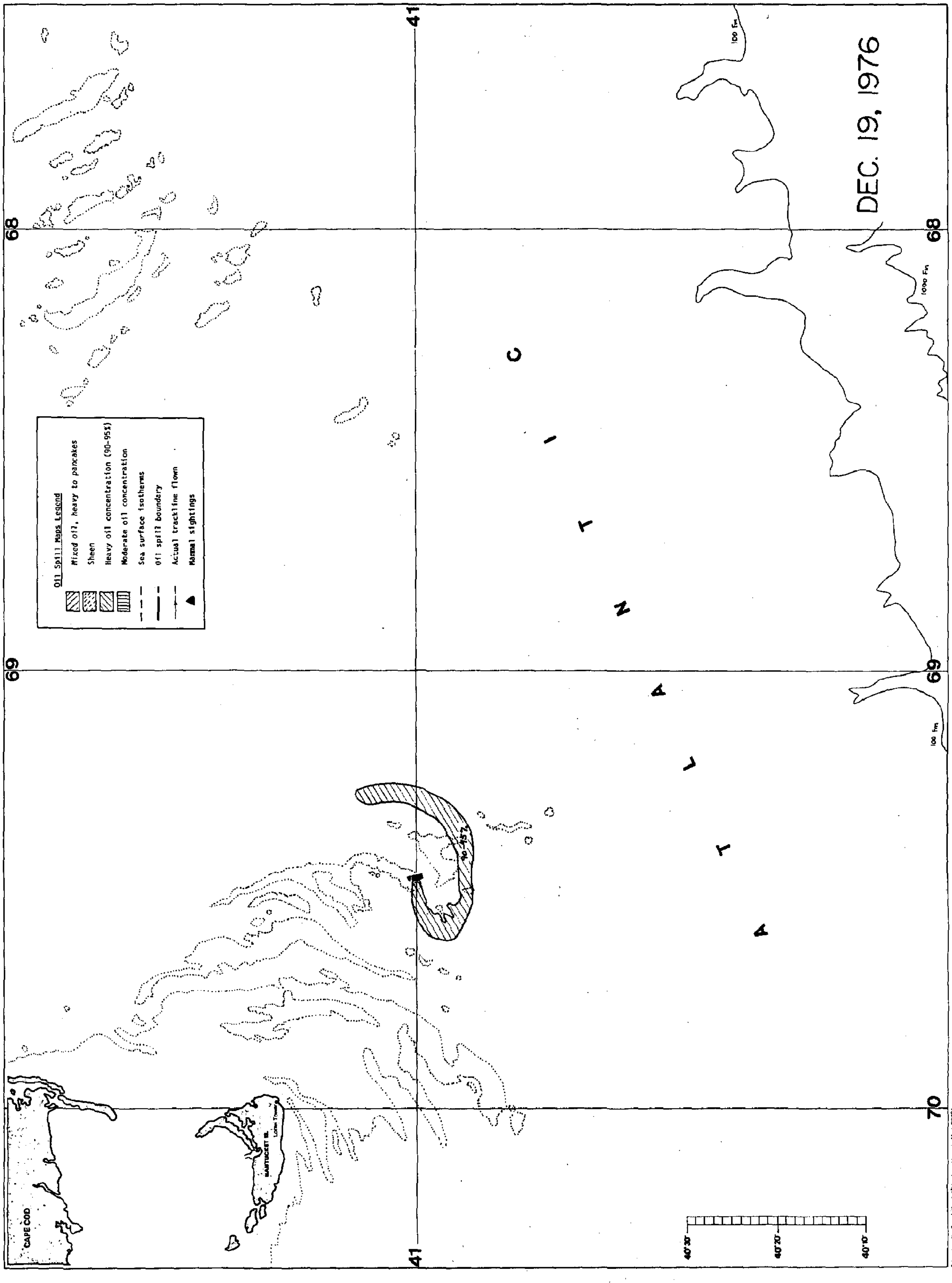
Oil Slick Maps

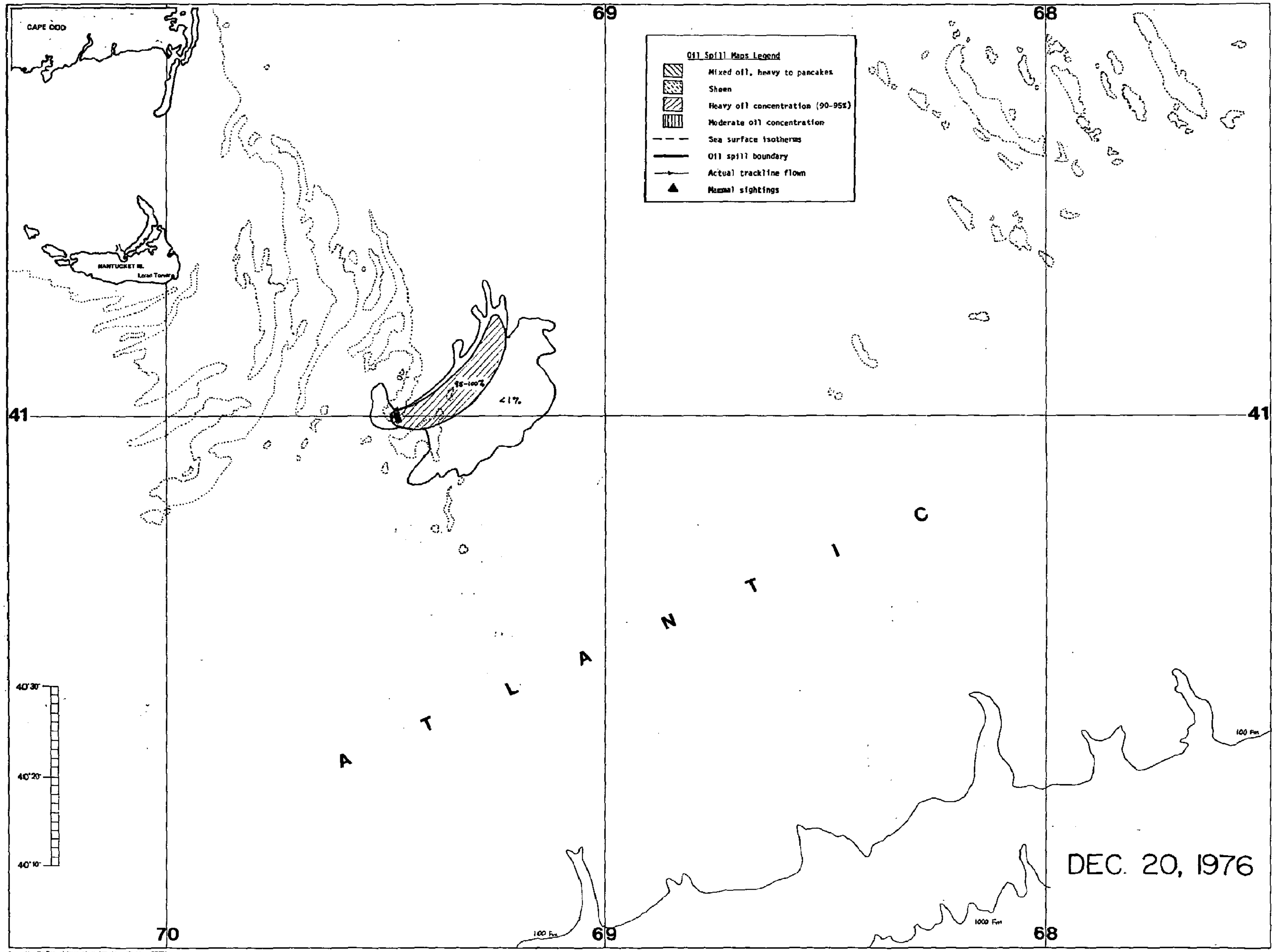
(Courtesy of U.S. Coast Guard; drafted by K. Kidwell, CEDDA, EDS, NOAA)

List of Maps

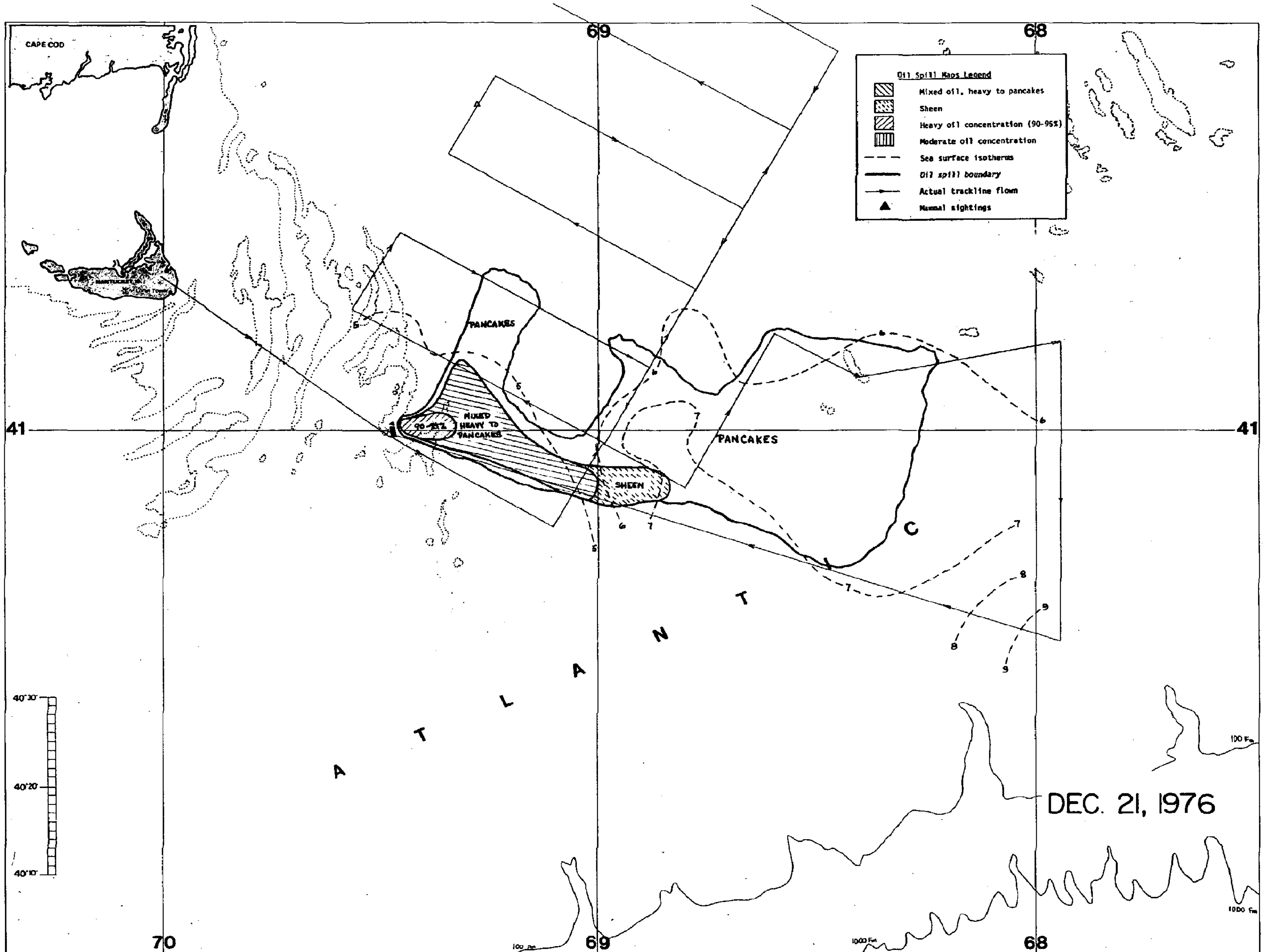

DEC. 17, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
ATLANTIC
CAPE COD
NANTUCKET IS.
100 Fm
1000 Fm
41
68
69
70
40°30'
40°20'
40°10'


DEC. 18, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
ATLANTIC
PANCAKES
CAPE COD
NANTUCKET IS.
100 Fm
1000 Fm
41
68
69
70
40°30'
40°20'
40°10'

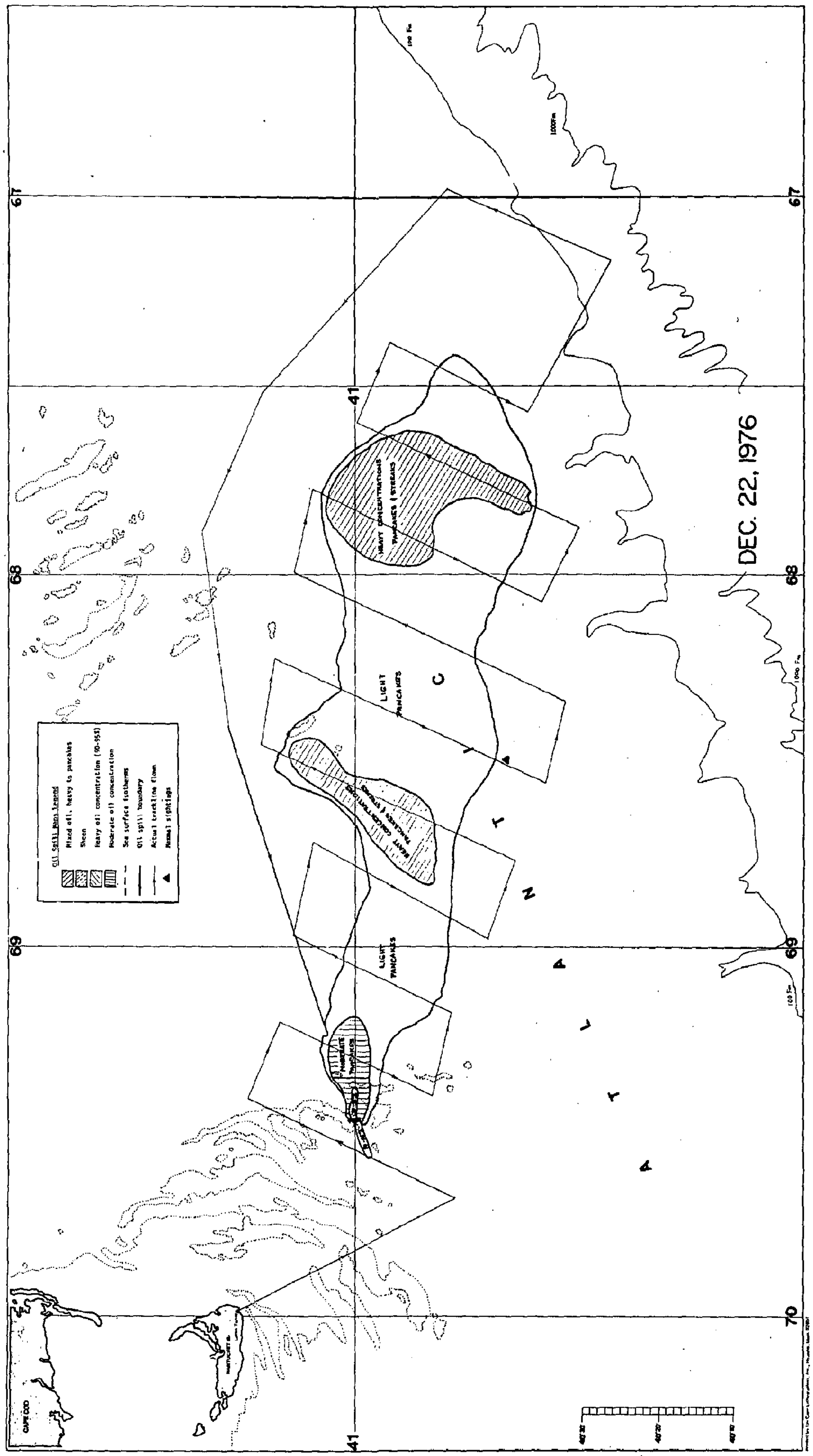

DEC. 19, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
ATLANTIC
CAPE COD
NANTUCKET IS.
100 Fm
1000 Fm
41
68
69
70
90-95%
40°30'
40°20'
40°10'

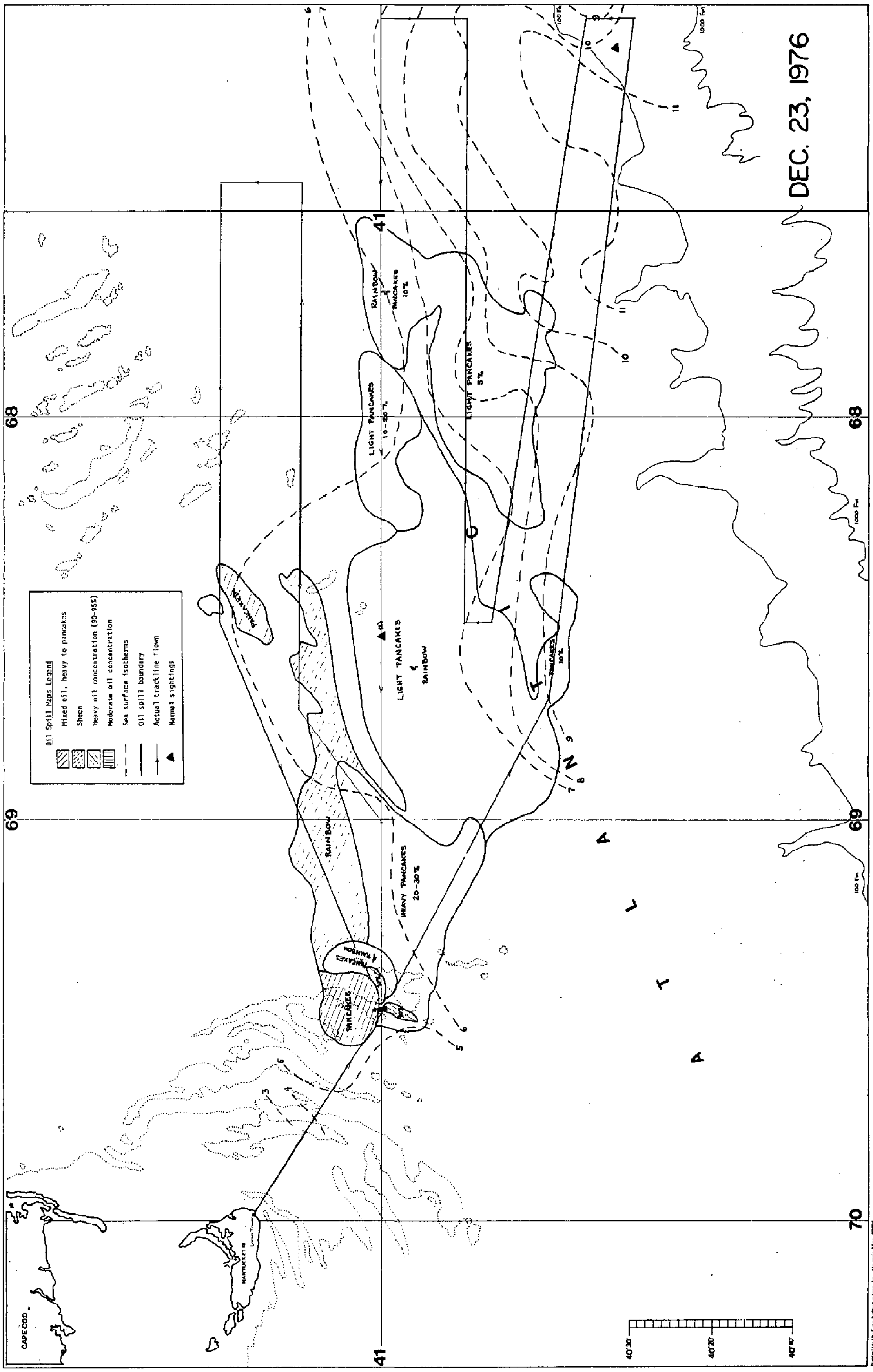


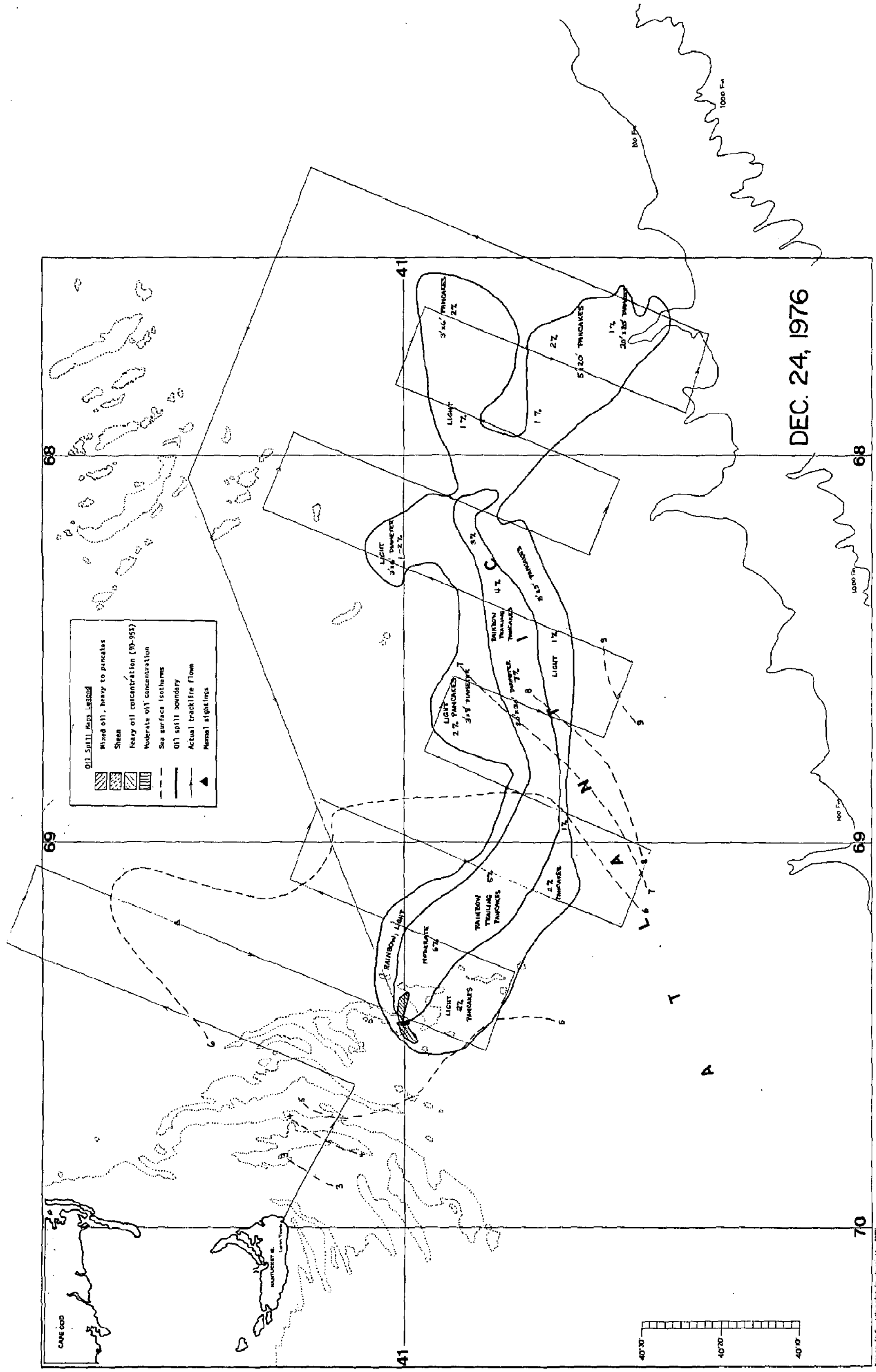
CAPE COD
NANTUCKET IS.
Loran Tower
69
68
70
41
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
95-100%
<1%
A T L A N T I C
100 Fm
1000 Fm
40°30'
40°20'
40°10'
DEC. 20, 1976

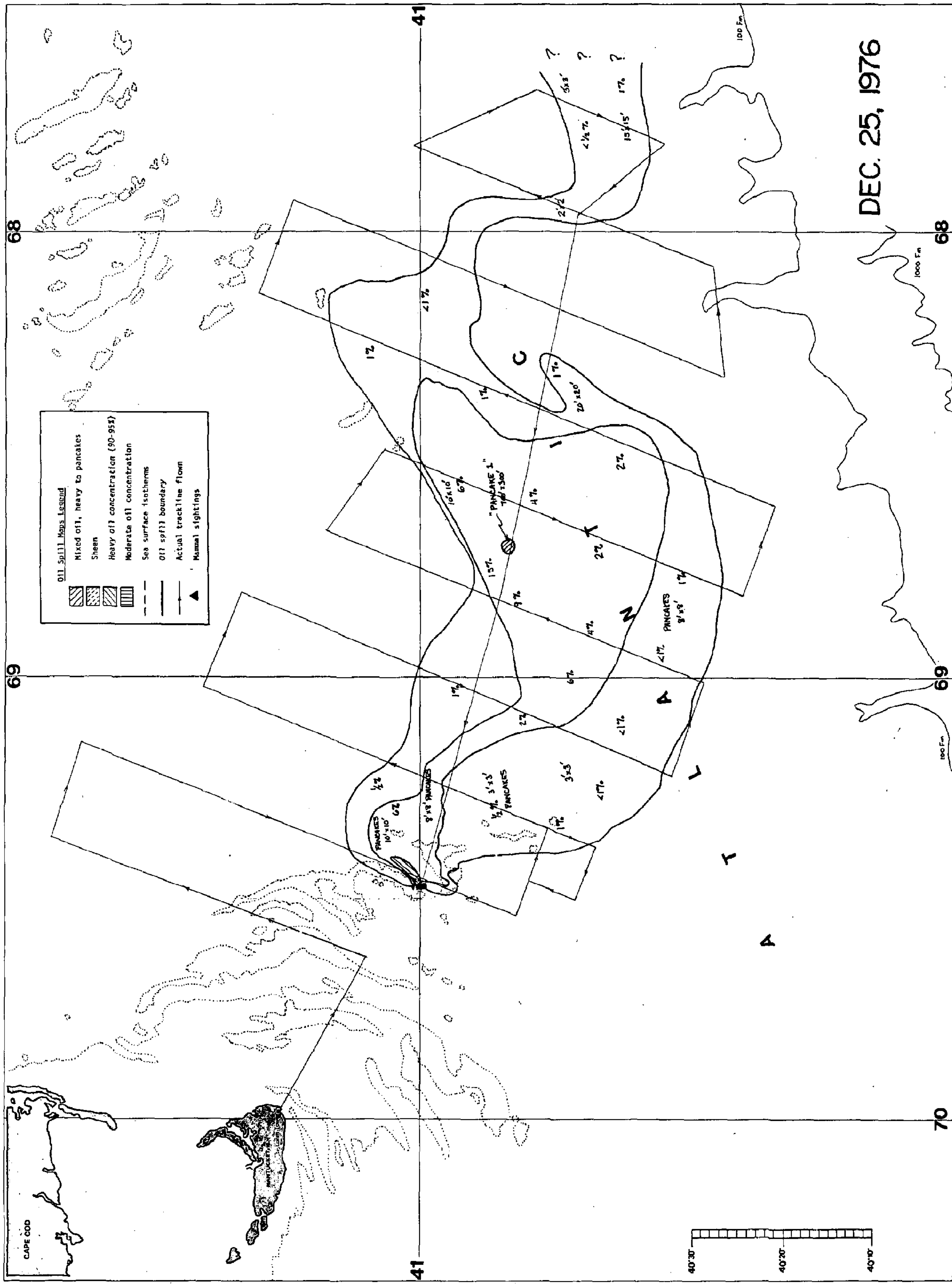


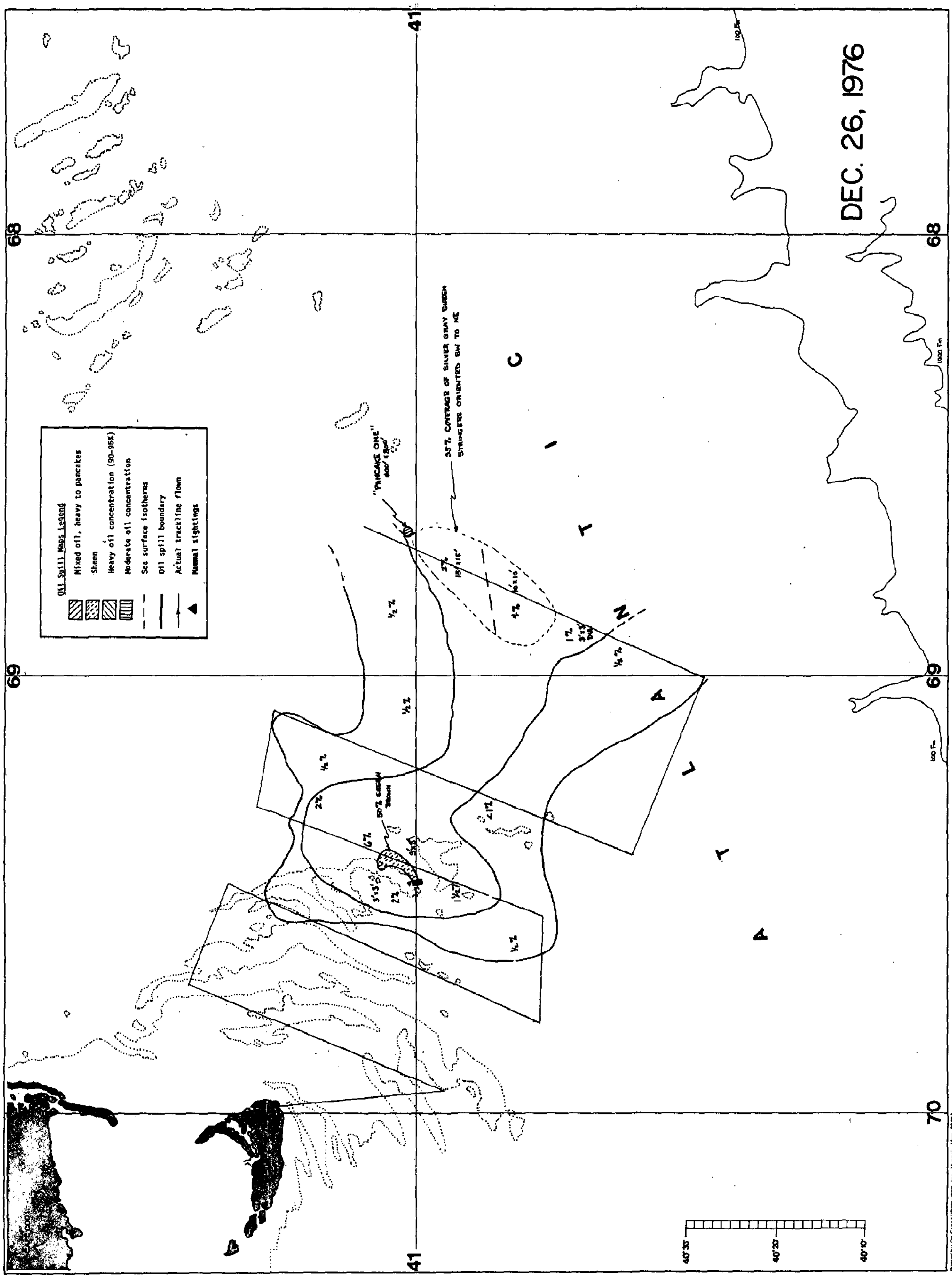
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
CAPE COD
PANCAKES
PANCAKES
MIXED HEAVY TO PANCAKES
SHEEN
A T L A N T I C
DEC. 21, 1976
100 Fm
1000 Fm
69
68
70
41
40°30'
40°20'
40°10'

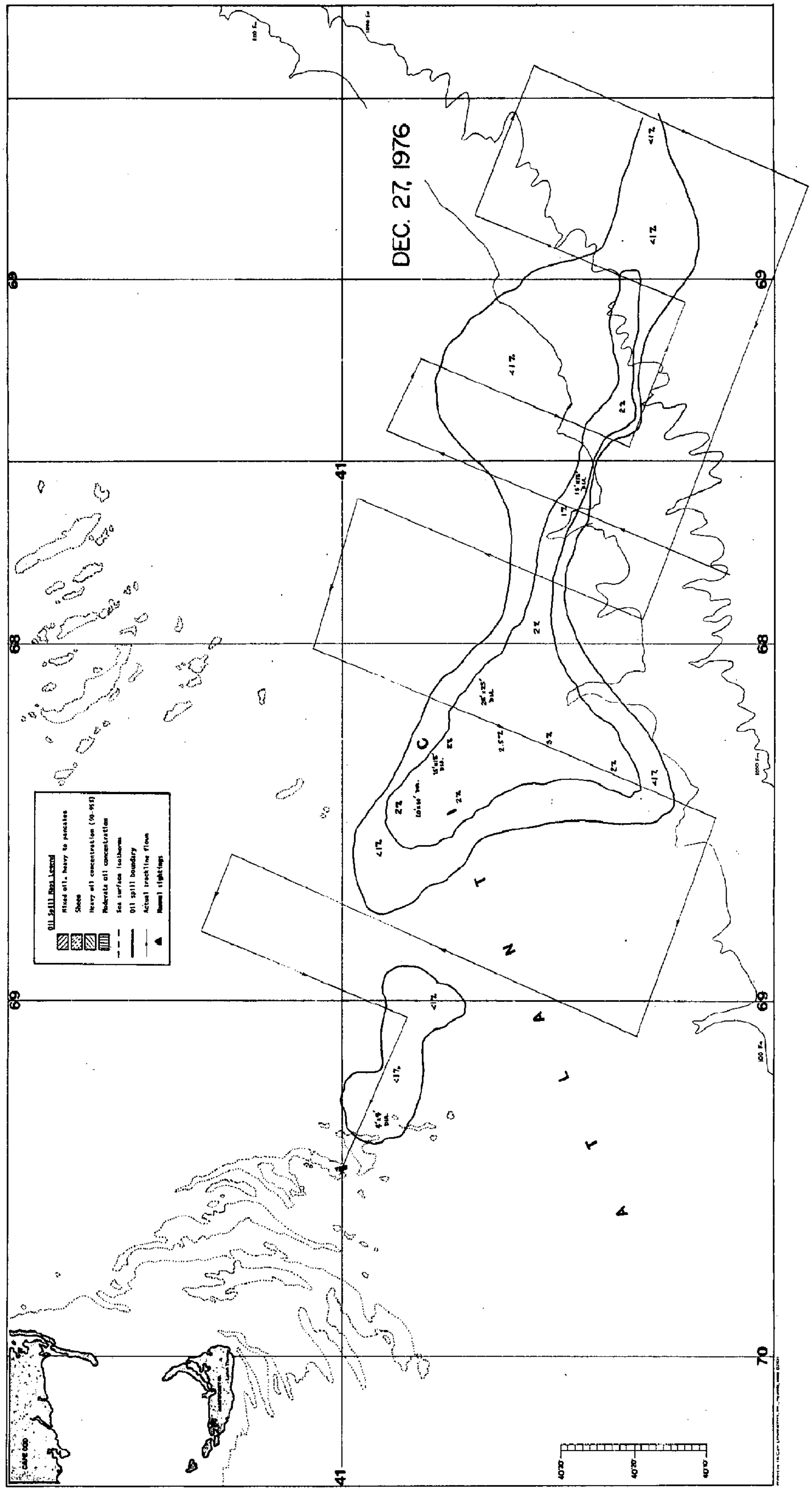

DEC. 22, 1976
67
68
69
70
41
LIGHT PANCAKES
HEAVY CONCENTRATIONS PANCAKES & STREAKS
MODERATE PANCAKES
A T L A N T I C
CAPE COD
NANTUCKET IS.
100 Fm
1000 Fm

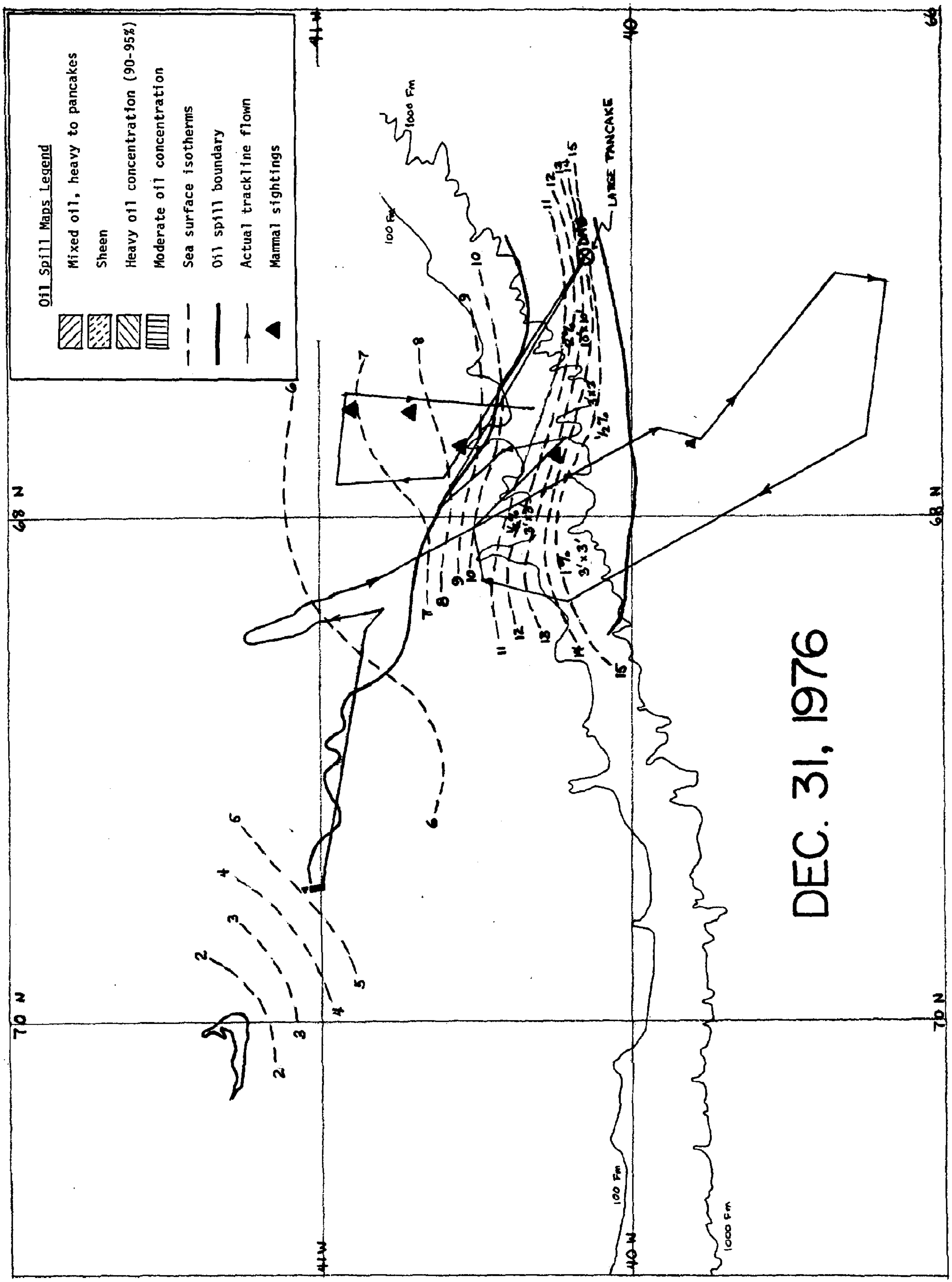

DEC. 23, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (30-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
LIGHT PANCAKES 10-20%
LIGHT PANCAKES 5%
RAINBOW & PANCAKES 10%
LIGHT PANCAKES & RAINBOW
HEAVY PANCAKES 20-30%
RAINBOW
PANCAKES
CAPE COD
A T L A N T I C
41
68
69
70


DEC. 24, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
CAPE COD
ATLANTIC
41
68
69
70

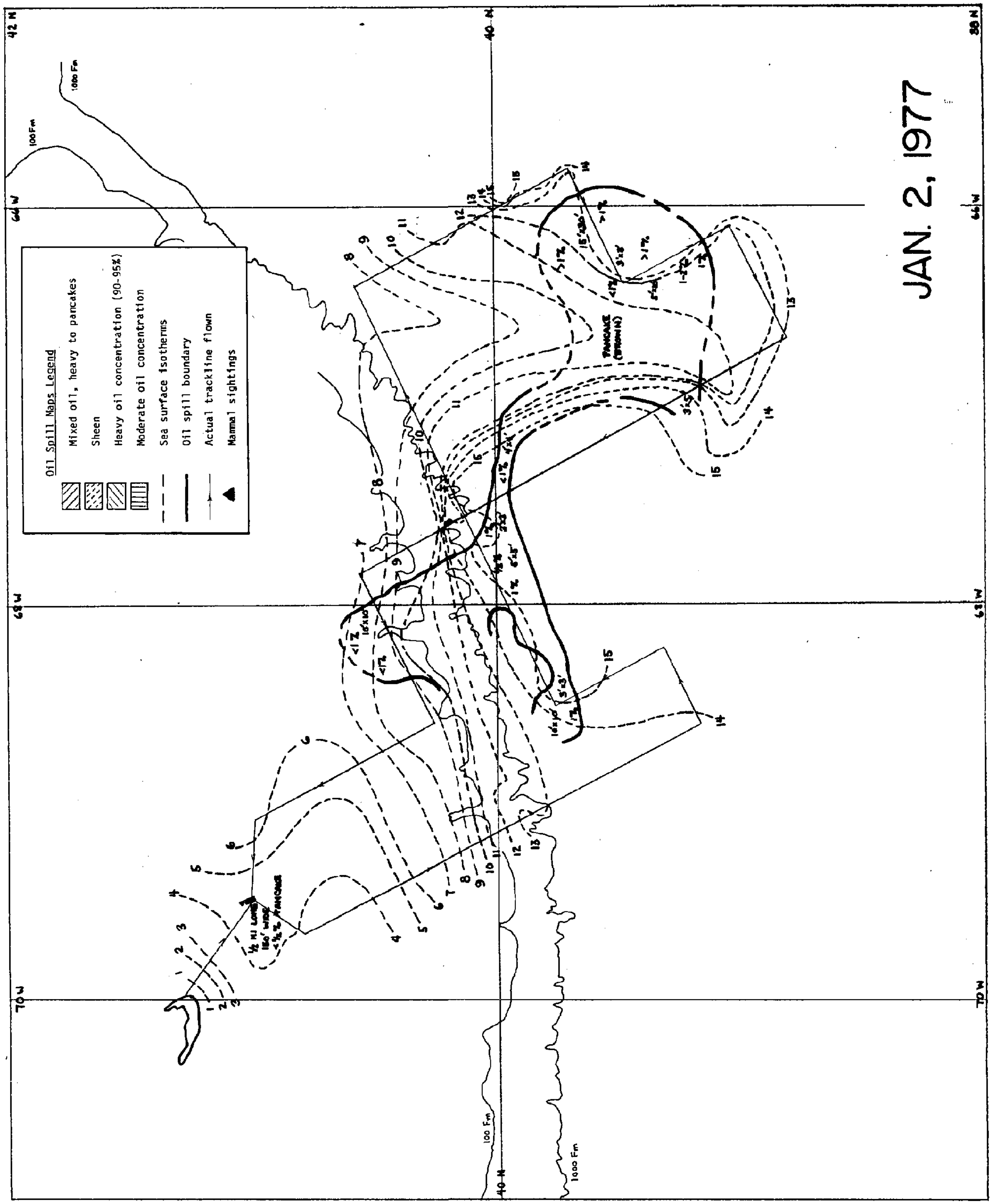

DEC. 25, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
"PANCAKE 1"
PANCAKES 8'x8'
PANCAKES 10'x10'
8'x8' PANCAKES
3'x3' PANCAKES
20'x20'
10'x10'
15'x15'
5'x5'
A T L A N T I C
CAPE COD
100 Fm
1000 Fm
41
68
69
70
40°30'
40°20'
40°10'

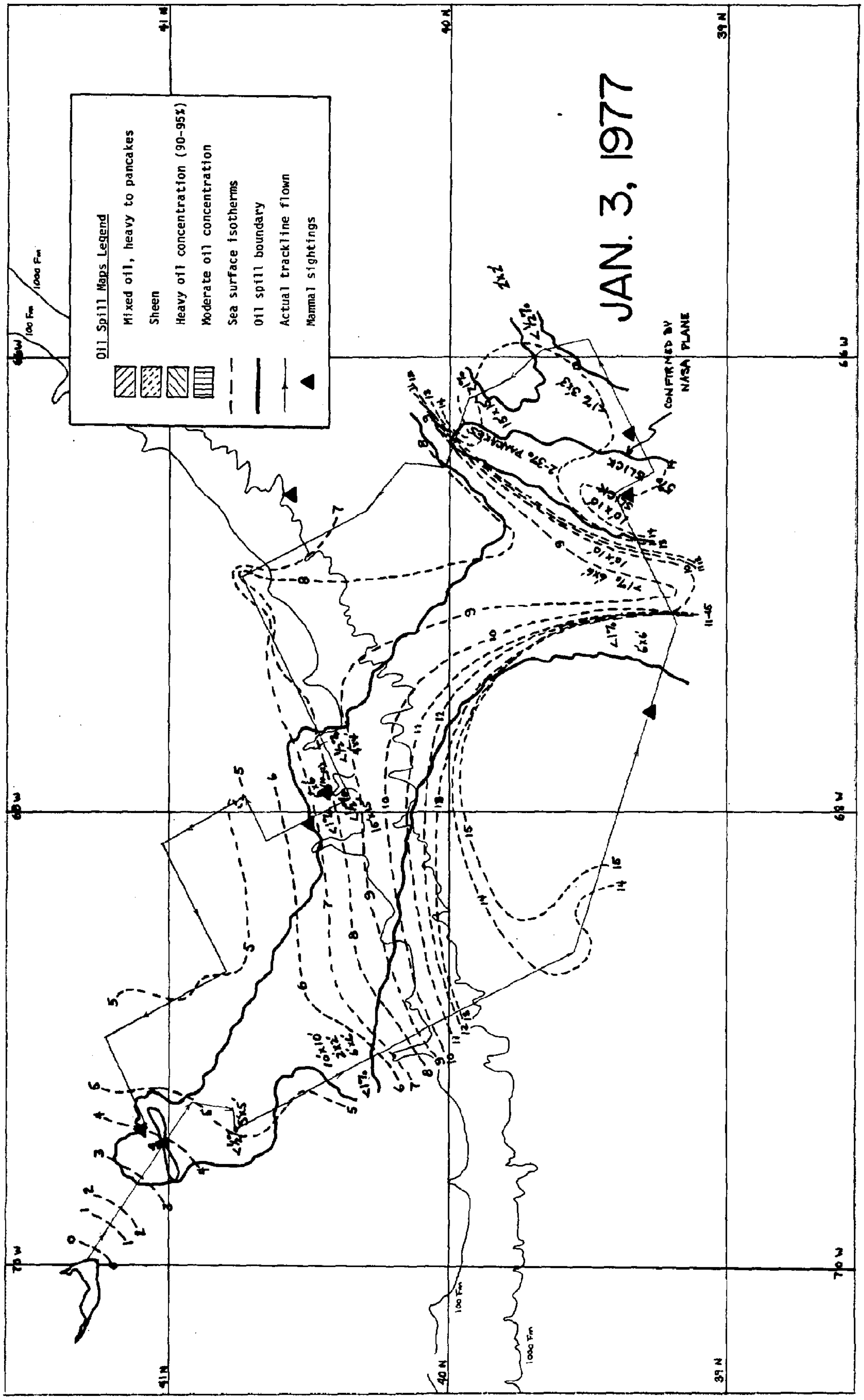

DEC. 26, 1976
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flow
Mammal sightings
"PANCAKE ONE"
35% COVERAGE OF SILVER GRAY SHEEN STRINGERS ORIENTED SW TO NE
A T L A N T I C
N
41
68
69
70


DEC. 27, 1976
ATLANTIC

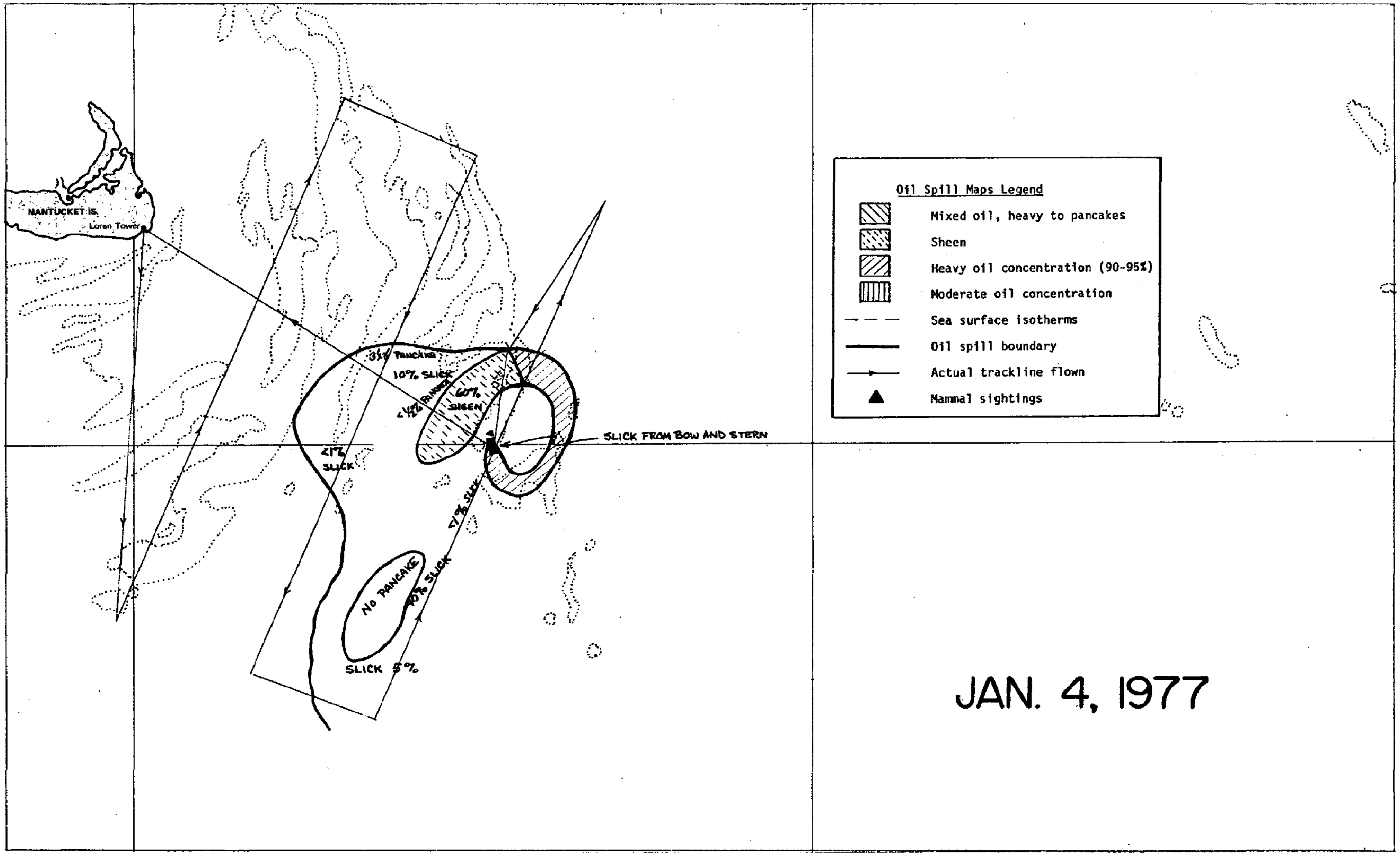


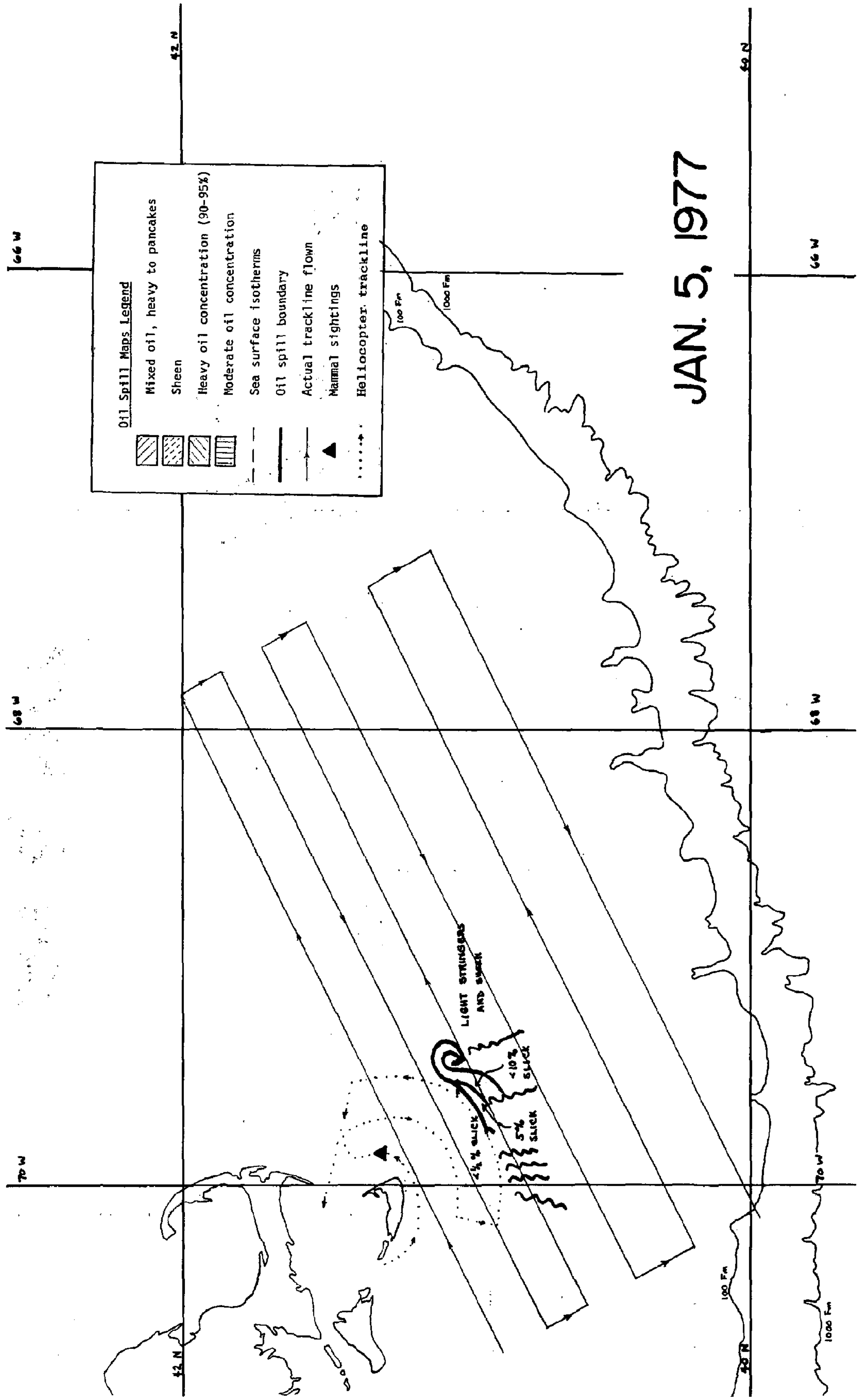
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
DEC. 31, 1976
LARGE PANCAKE
100 Fm
1000 Fm
70 N
68 N
69
41 W
40 N

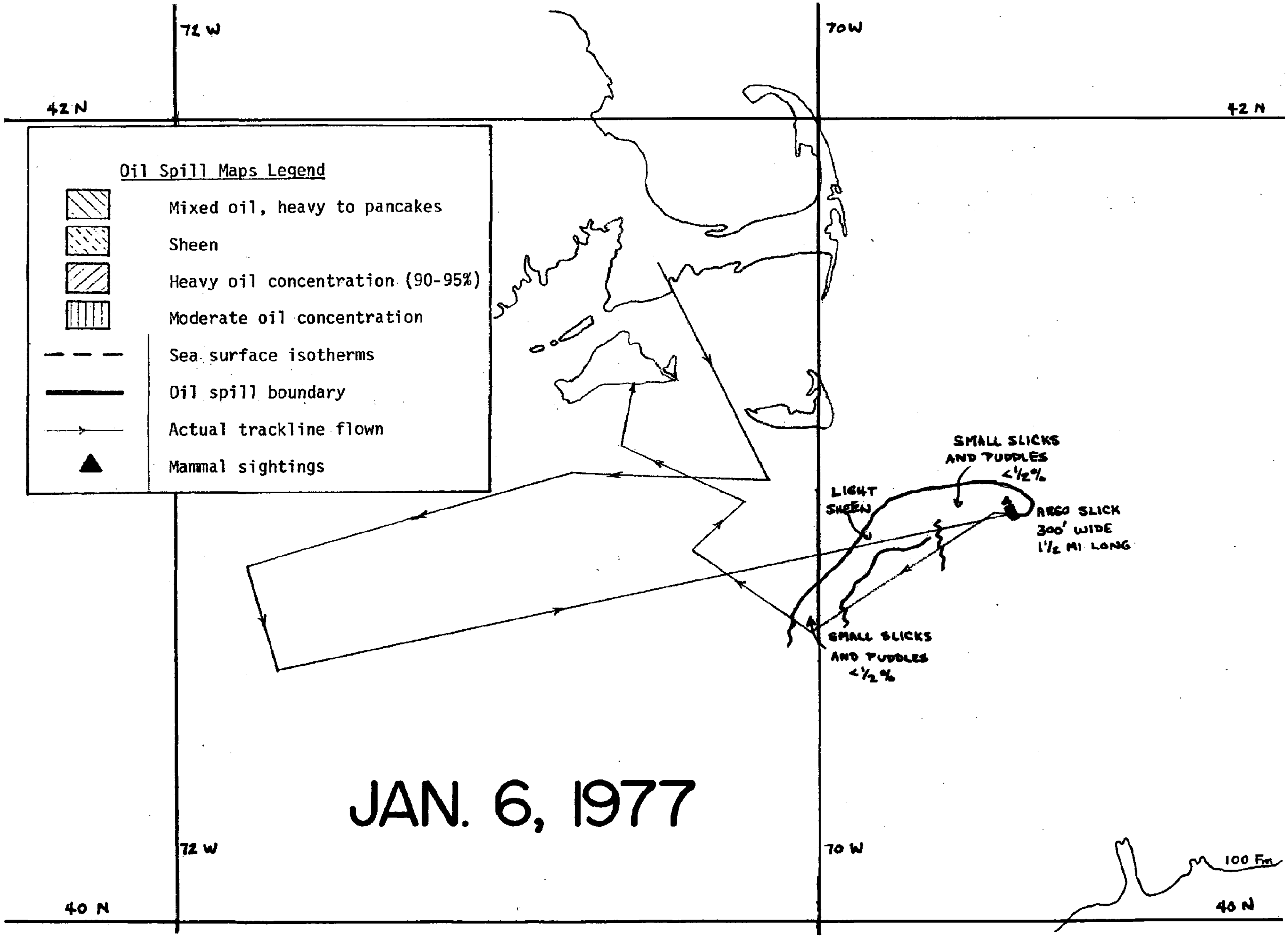

Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
JAN. 2, 1977
42 N
40 N
38 N
66 W
68 W
70 W
100 Fm
1000 Fm

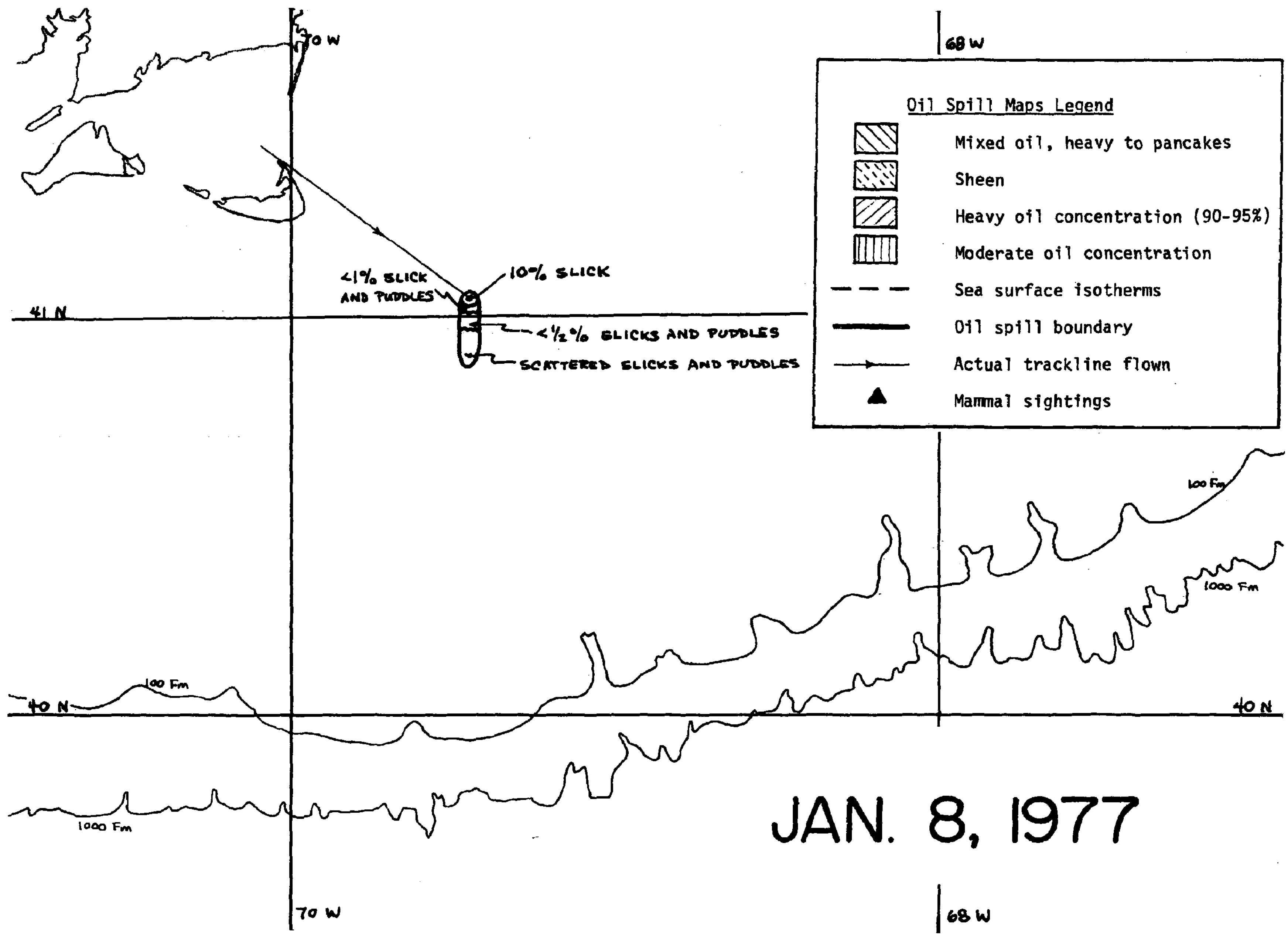


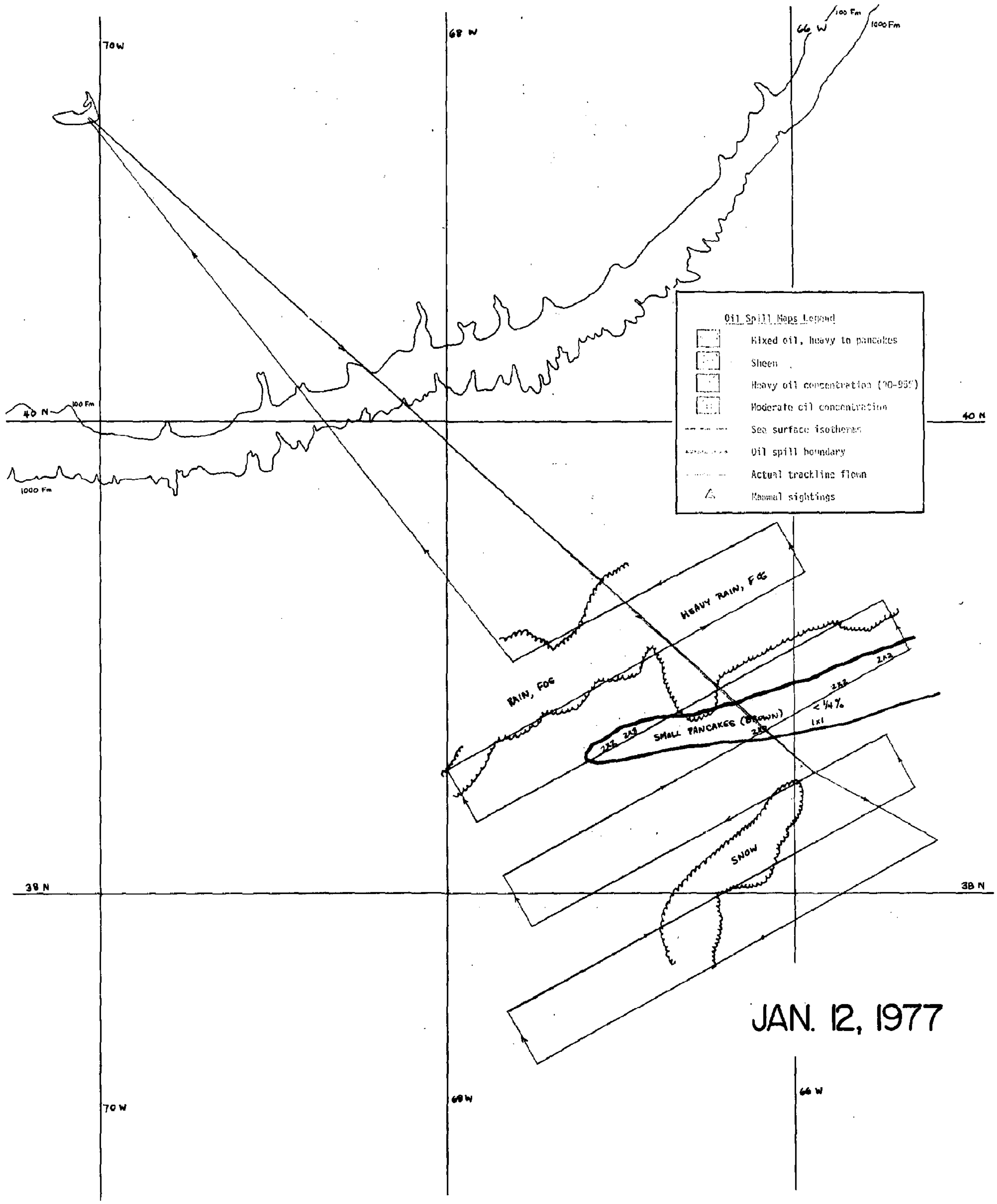
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
JAN. 3, 1977
CONFIRMED BY NASA PLANE
41 N
40 N
39 N
70 W
69 W
68 W
67 W
66 W
100 Fm
1000 Fm

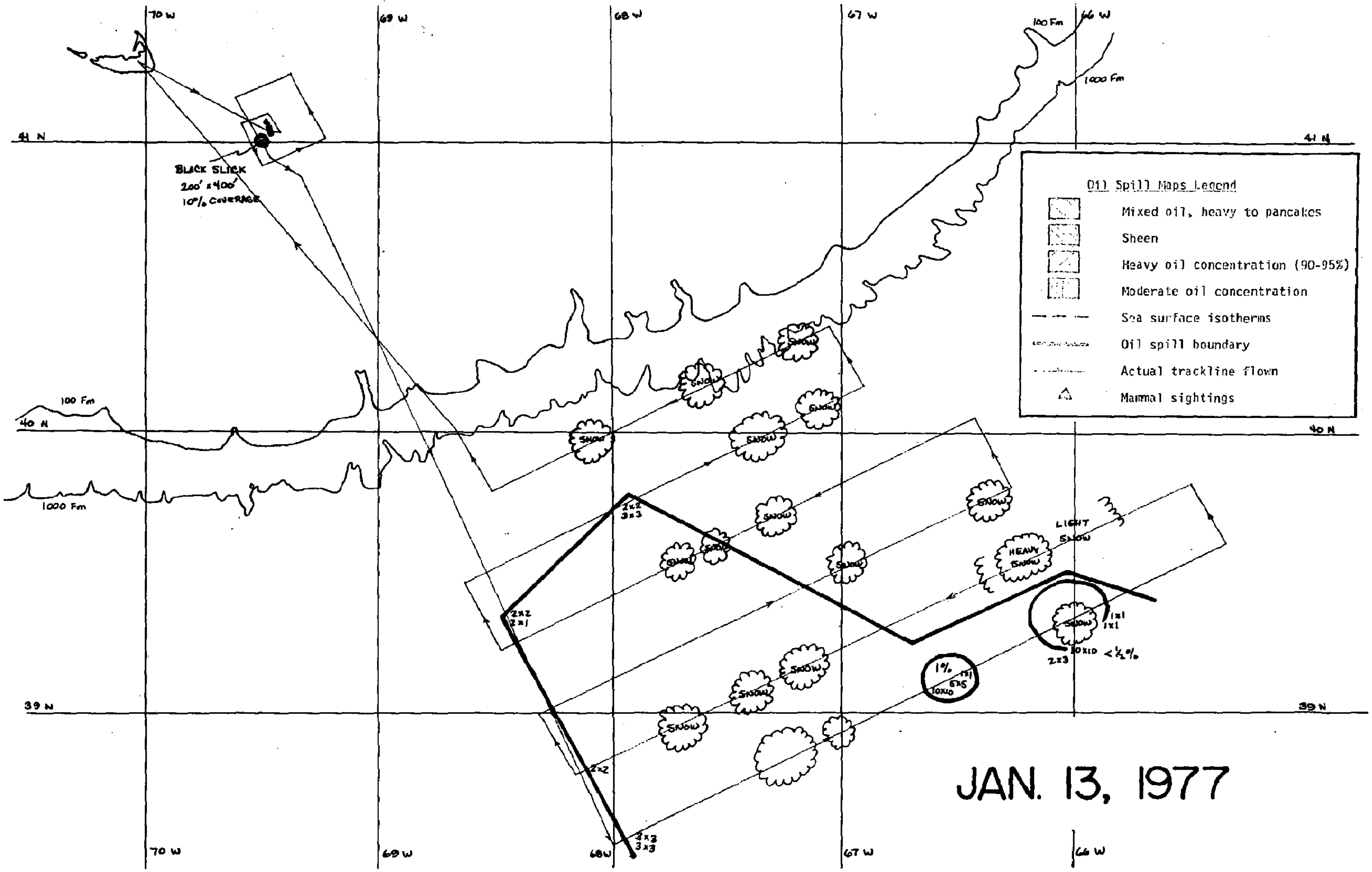

Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
NANTUCKET IS.
Loran Tower
SLICK FROM BOW AND STERN
10% SLICK
60% SHEEN
<1% SLICK
NO PANCAKE
SLICK 5%
JAN. 4, 1977

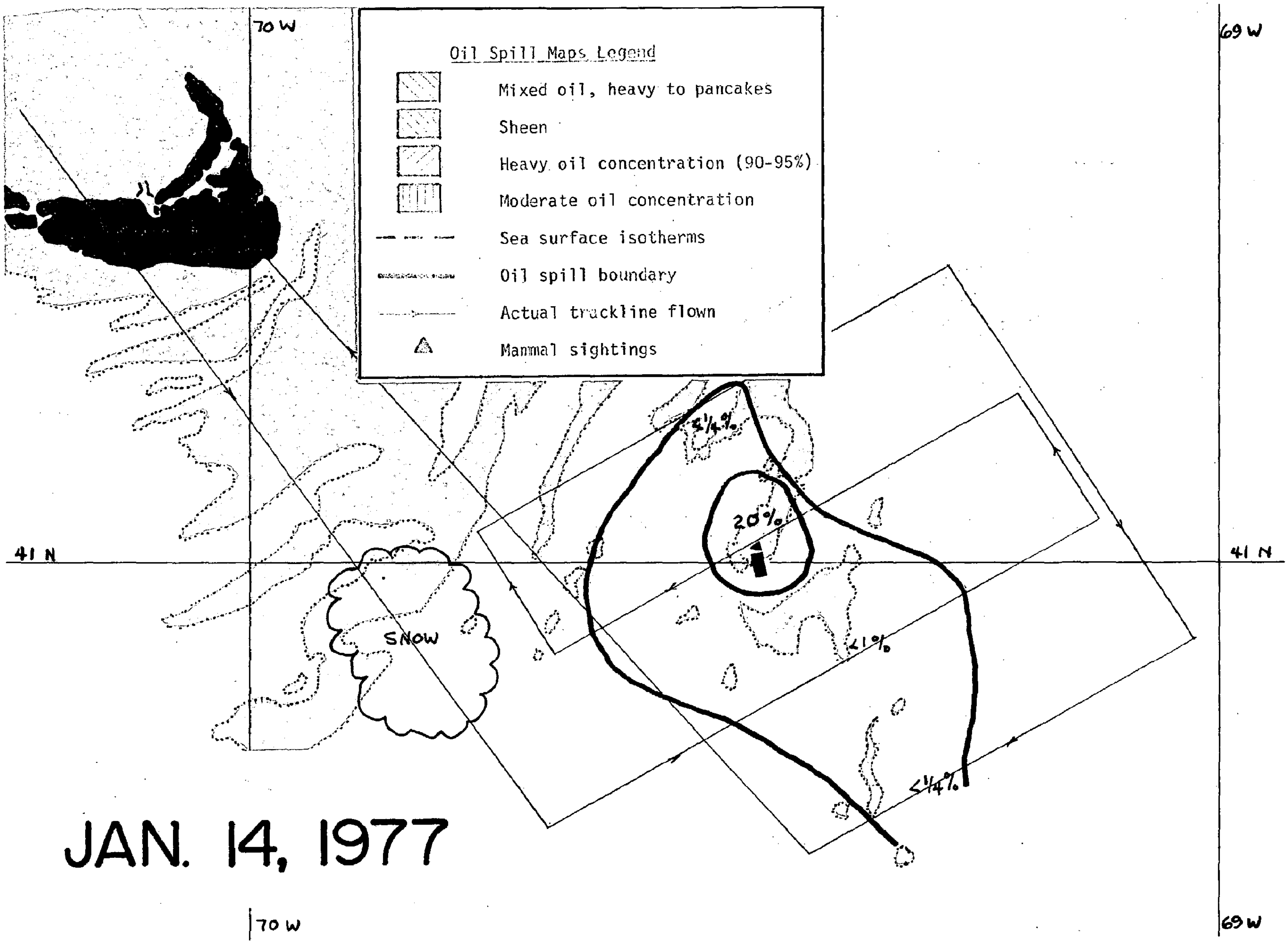

JAN. 5, 1977
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
Helicopter trackline
42 N
40 N
66 W
68 W
70 W
100 Fm
1000 Fm
<10% SLICK
5% SLICK

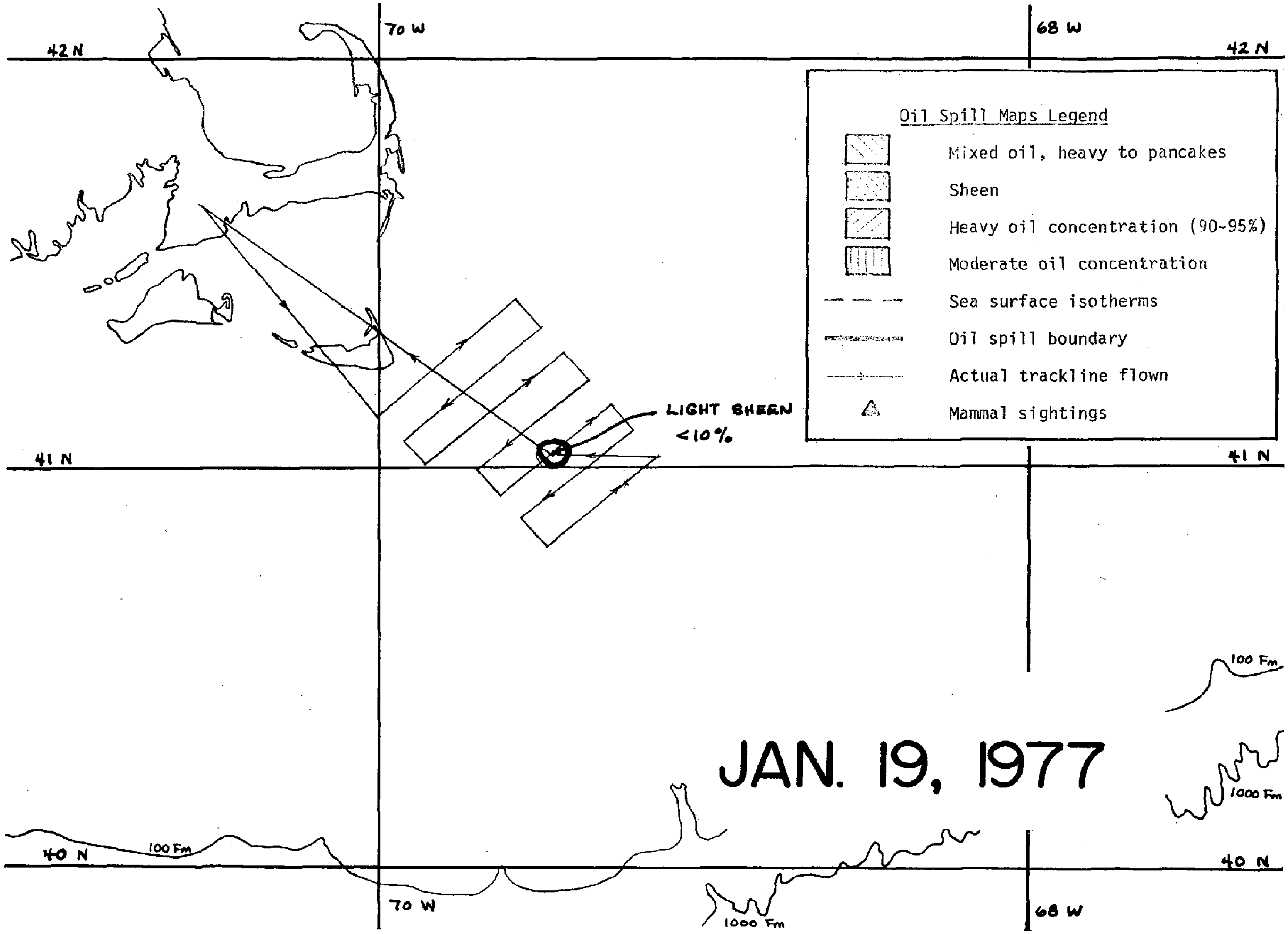

72 W
70 W
42 N
42 N
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
SMALL SLICKS
AND PUDDLES
<1/2%
LIGHT
SHEEN
ARGO SLICK
300' WIDE
1 1/2 MI LONG
SMALL SLICKS
AND PUDDLES
<1/2%
JAN. 6, 1977
72 W
70 W
100 Fm
40 N
40 N

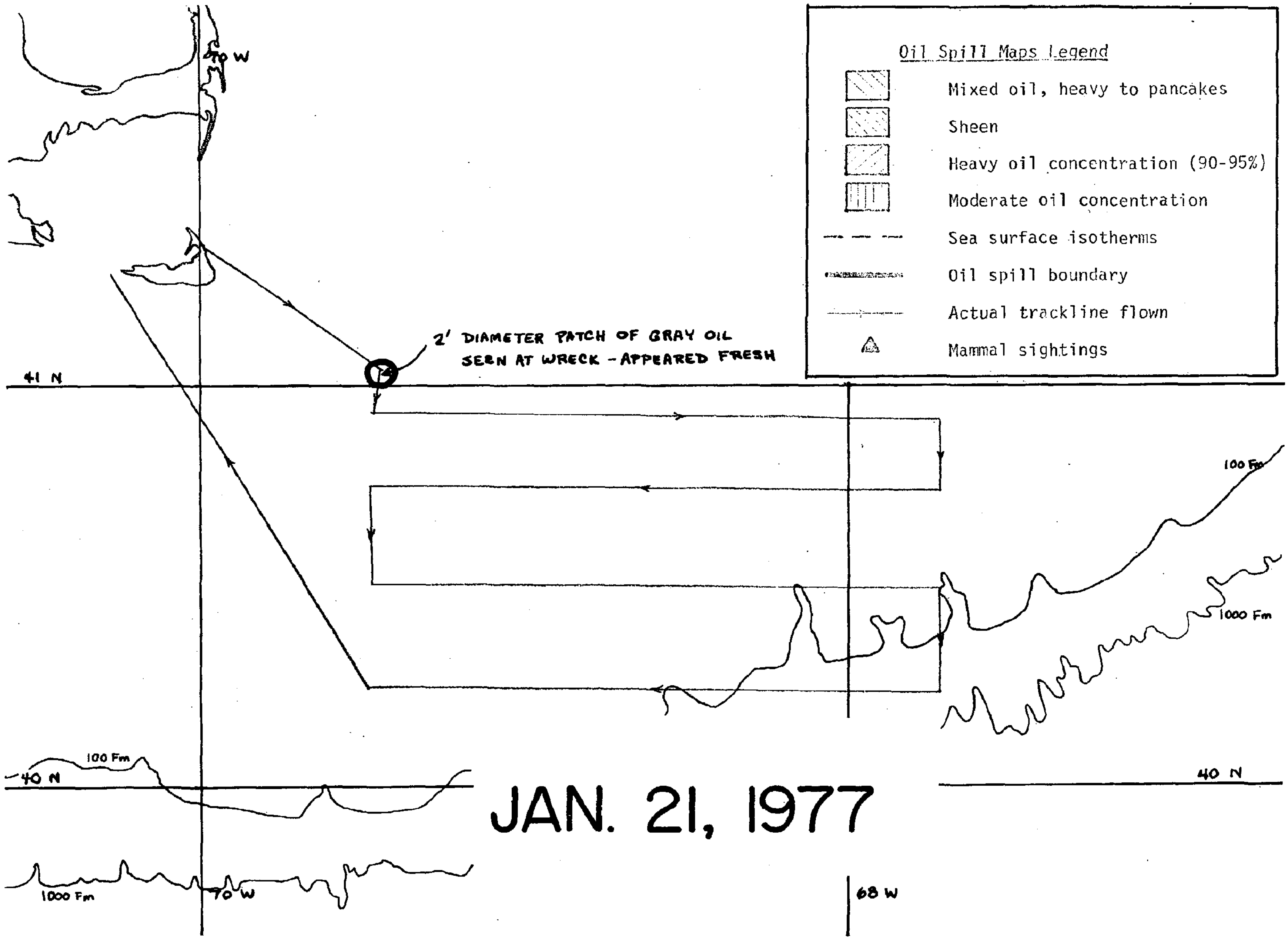

70 W
68 W
41 N
40 N
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
<1% SLICK AND PUDDLES
10% SLICK
<½% SLICKS AND PUDDLES
SCATTERED SLICKS AND PUDDLES
100 Fm
1000 Fm
JAN. 8, 1977

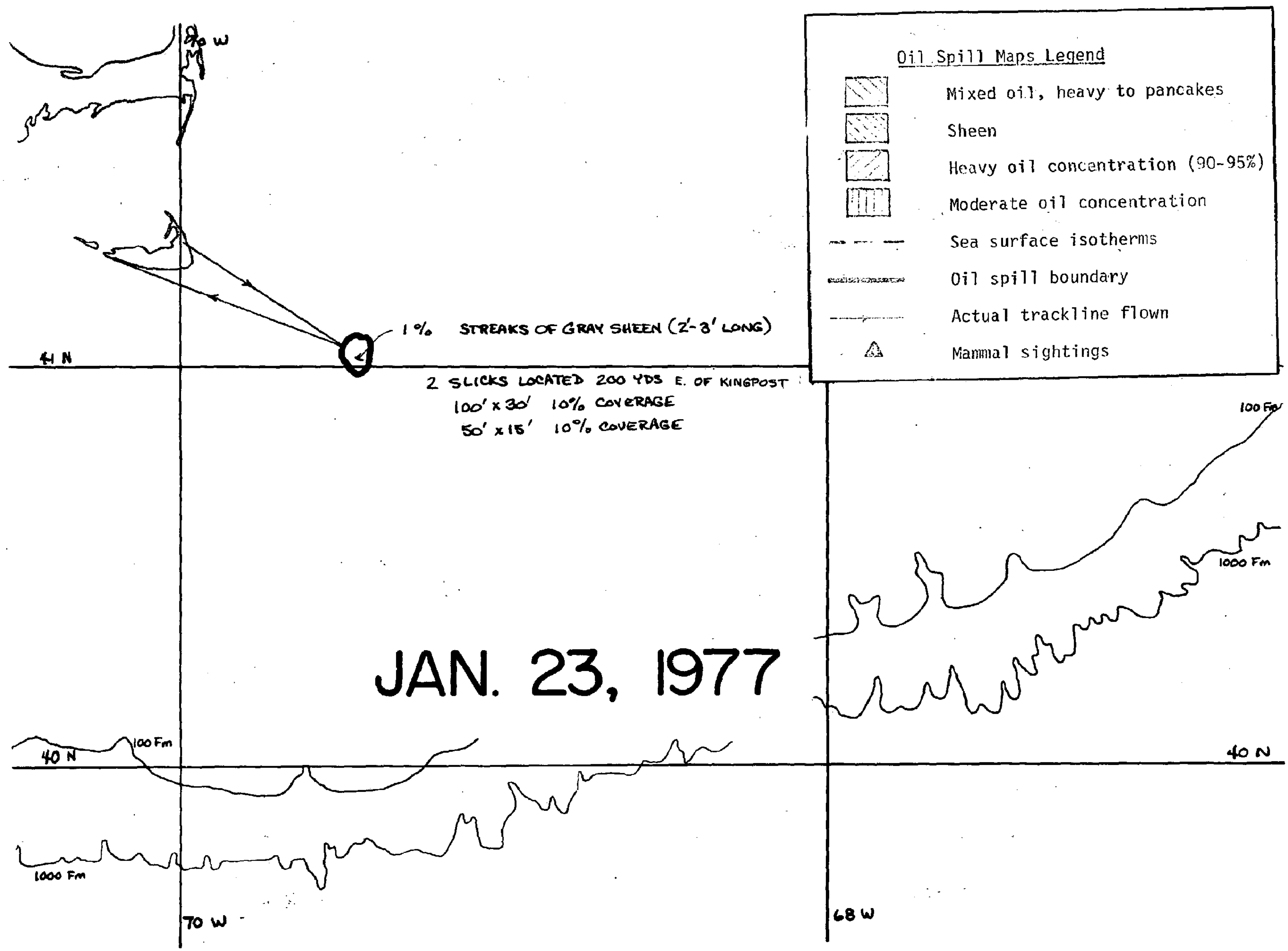

70 W
68 W
66 W
100 Fm
1000 Fm
40 N
38 N
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
HEAVY RAIN, FOG
RAIN, FOG
SMALL PANCAKES (BROWN)
< 1/4 %
SNOW
JAN. 12, 1977

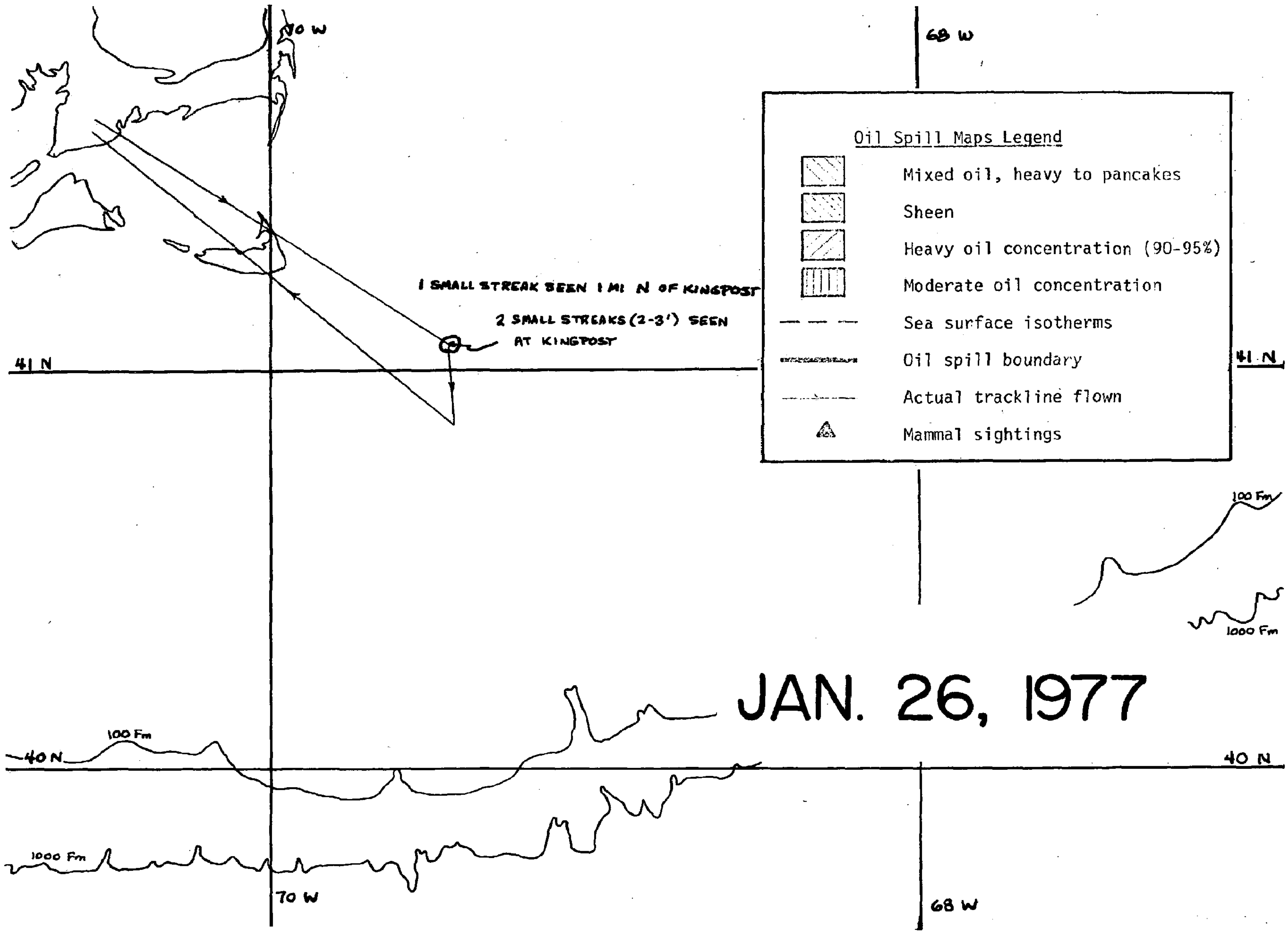

Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
70 W
69 W
68 W
67 W
66 W
41 N
40 N
39 N
100 Fm
1000 Fm
BLACK SLICK
200' x 400'
10% COVERAGE
SNOW
HEAVY SNOW
LIGHT SNOW
2x2
3x3
2x1
1x1
2x3
10x10 <½%
1%
5x5
10x10
JAN. 13, 1977

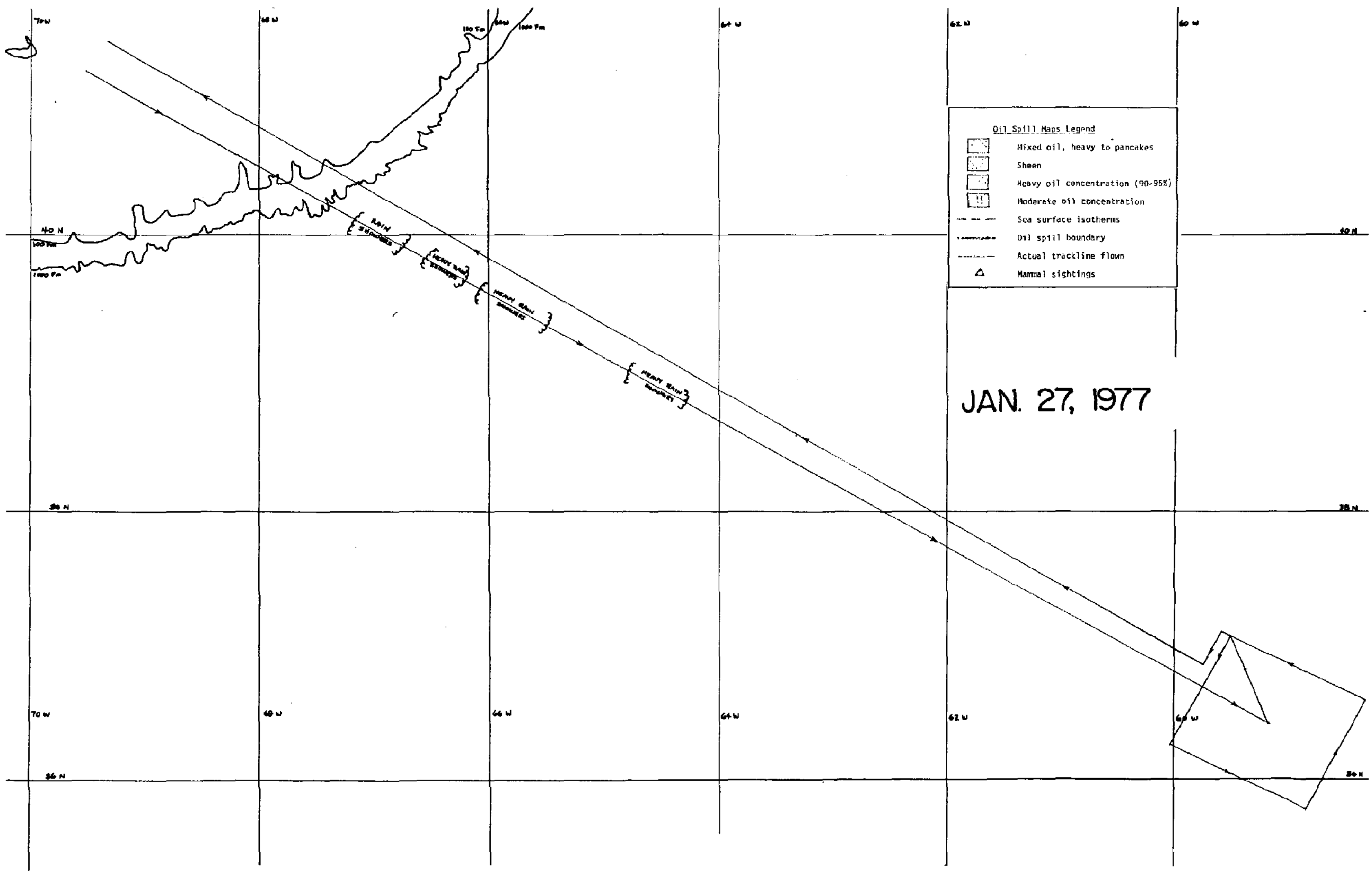

70 W
69 W
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
41 N
41 N
SNOW
20%
≤1/4%
<1%
<1/4%
JAN. 14, 1977
70 W
69 W


70 W
68 W
42 N
42 N
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
LIGHT SHEEN
<10%
41 N
41 N
100 Fm
JAN. 19, 1977
1000 Fm
40 N
100 Fm
40 N
70 W
1000 Fm
68 W


Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
2' DIAMETER PATCH OF GRAY OIL SEEN AT WRECK - APPEARED FRESH
41 N
40 N
70 W
68 W
100 Fm
1000 Fm
JAN. 21, 1977


70 W
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
1 % STREAKS OF GRAY SHEEN (2'-3' LONG)
41 N
2 SLICKS LOCATED 200 YDS E. OF KINGPOST
100' x 30' 10% COVERAGE
50' x 15' 10% COVERAGE
100 Fm
1000 Fm
JAN. 23, 1977
40 N
100 Fm
40 N
1000 Fm
70 W
68 W


70 W
68 W
41 N
40 N
100 Fm
1000 Fm
1 SMALL STREAK SEEN 1 MI N OF KINGPOST
2 SMALL STREAKS (2-3') SEEN AT KINGPOST
Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
JAN. 26, 1977


Oil Spill Maps Legend
Mixed oil, heavy to pancakes
Sheen
Heavy oil concentration (90-95%)
Moderate oil concentration
Sea surface isotherms
Oil spill boundary
Actual trackline flown
Mammal sightings
JAN. 27, 1977
70 W
68 W
66 W
64 W
62 W
60 W
40 N
38 N
36 N
100 Fm
1000 Fm
RAIN SHOWERS
HEAVY RAIN SHOWERS
HEAVY RAIN SHOWERS
HEAVY RAIN SHOWERS

APPENDIX V

Cruise Reports

List of Cruises

R/V *OCEANUS* CRUISES 19 AND 20

Argo Merchant Oil Spill Cruises: Samples for Hydrocarbon Analyses

John W. Farrington
Associate Scientist, Chemistry Department

and

John M. Teal
Senior Scientist, Biology Department

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

<u>Participating Scientists</u>

R/V *Oceanus* Cruise 19:	John W. Farrington, WHOI John M. Teal, WHOI Richard Jademac, USCG R&D Center Ted Van Fleet, URI,GSO
R/V *Oceanus* Cruise 20:	John W. Farrington, WHOI John M. Teal, WHOI Neil Moseman, ERCO
WHOI	Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543
USCG R&D Center	U.S. Coast Guard Research and Development Center Groton, Connecticut
URI,GSO	University of Rhode Island Graduate School of Oceanography Kingston, Rhode Island 02881
ERCO	Energy Resources Company 185 Alewife Brook Parkway Cambridge, Massachusetts 02138

Introduction

The intent of the sampling and preliminary sample treatment was to allow analyses for detecting high levels of oil contamination from the *Argo Merchant* oil spill, or to provide background data prior to the arrival of spilled oil in the area, eventually resulting in high concentrations in water and/or sediments. High concentrations in this context are 50 micrograms/liter of water or more and between 10 and 100 micrograms/gram dry weight of sediment or more, depending on sediment type.

The personnel participating in the cruises were fully aware that the gear being used was not optimal for obtaining samples for low level hydrocarbon analyses in water. Suitable sampling devices were not available at the time of the cruise.

Special Samples - R/V *Oceanus* Cruise 20

One sample of OC 20/13 surface tar at station 13 was obtained by stainless steel bucket. This sample was scraped from the bucket with a stainless steel spatula rinsed with ethanol. The tar was transferred to a 0.32-ounce, precleaned glass jar with aluminum foil cap. After equilibrating with the main laboratory temperature the tar flowed like honey down the jar, coating its inside. Total volume of tar was about 100 milliliters.

Two vials of R/V *Oceanus* fuel were obtained for passive tagging comparison in the event samples were contaminated with the ship's fuel.

Sediment Sampling and Storage Procedure

Sediment samples were taken with a 1/25 m^2 Van Veen grab sampler mounted on a circular based frame, which insures perpendicular penetration. The sampler was lowered near the bottom at about 10 meters/minute until the sheave on the winch post slacked. The sampler was gently drawn out and returned to deck at 10 to 20 meters/minute. Once on deck, the grab was lowered to rest on a stainless steel bucket that had been precleaned with sea water and several rinses of ∿100 milliliters each of ethanol from a polyethylene squeeze bottle. The grab was emptied into the bucket by opening the top doors and forcing the sediment out the bottom of the one-third to one-half opened grab with a stainless steel bucket and subsampled. About two one-quarter portions of the sample were placed in glass jars with aluminum foil lined caps, with aluminum foil placed in them between the glass jar and the cap. These operations were all conducted on the main deck of R/V *Oceanus* near the starboard access hatch to the main laboratory. The samples were then placed in the main laboratory in a freezer maintained at -10 to -20°C. After return to Woods Hole the samples were transferred to another chest freezer in the barn freezer storage area at Woods Hole Oceanographic Institution and maintained at -10 to -20°C.

The jars these sediments were stored in had been precleaned prior to the cruise as follows: soap wash, water rinse, acetone rinse, and distilled pentane rinse.

Water Sampling and Storage Procedure

Samples were obtained from a rosette sampling system consisting of 30-liter G/O bottles, a temperature sensor, and a transmissometer. Details can be obtained from Dave Folger, USCG, Woods Hole, or John Milliman, Geology and Geophysics Department, WHOI.

Approximately 3-liter water samples were drawn from the 30-liter G/O bottles directly into a brown glass 1-gallon bottle. These bottles had previously contained glass distilled petroleum ether, n-hexane, or nanograde methylene chloride. After the samples had been drawn from the G/O bottle on the fantail of the *Oceanus*, the 1-gallon bottles were carried into the main laboratory. Within 30 minutes, 100 milliliters of nanograde methylene chloride were added to the sample, and the sample shaken by hand in a horizontal position for 1 minute as determined by the main laboratory clock. The samples were then allowed to sit for 20 to 60 minutes. The water was then emptied via a 500-milliliter graduated cylinder, which was used to measure the water volume. The water-CH_2Cl_2 interface and methylene chloride were emptied into either 16- or 32-ounce jars. The bottle was rinsed with 20 to 30 milliliters of CH_2Cl_2 and the rinse added to the sample extract in the 16- or 32-ounce jar. The CH_2Cl_2 extract plus water interface was capped with foil between the cap and the glass jar and sample extract.

Several of the water samples were saved for extraction efficiency testing with the (approximately) 3 liters of water and 100 millilters of CH_2Cl_2 in the 1-gallon brown jug. The samples and sample extracts were stored at room temperature.

Several blanks were obtained during the two cruises. These consisted of adding 100 milliliters of CH_2Cl_2 to 1-gallon empty bottles and shaking for 1 minute, pouring off CH_2Cl_2 of 16- or 30-ounce jars, and then rinsing the bottle with 20 to 30 milliliters of CH_2Cl_2.

A sample of deck washings from R/V *Oceanus* was taken by running seawater over the deck and collecting this water as it ran off over the side. This sample of about 2.5 liters was poured from a stainless steel bucket into a 1-gallon brown bottle, and 100 millilters of CH_2Cl_2 were added. This sample was deemed necessary due to rain and melted snow runnoff from the deck at several points during cruise 20.

Sediment Samples for Hydrocarbon Analyses

R/V *Oceanus* Cruise 19

Station 1 — Water depth = 81-82 meters
Three grab samples -- labeled sample 1, sample 2, sample 3. Two 32-ounce jars of sediment each grab. Quantity of sediment in jars varied depending on grab size.

Station 2 — Water depth = 125 meters
Two grab samples -- labeled sample 1 and sample 2. Two 32-ounce jars of sediment from each grab. Quantity of sediment in jars varied depending on grab size.

R/V *Oceanus* Cruise 20

Station 1 — Water depth = 21.5 meters
Three grabs (A,B,C); two 32-ounce jars sediment from each grab.

Station 2 — Water depth = 28 meters
Three grabs (A,B,C); one 64-ounce jar of sediment from each grab.

Station 3 — Water depth = 38 meters
Three grabs (A,B,C); one 64-ounce jar of sediment from each grab.

Station 4 — Water depth = ? (see USGS records)
Three grabs (A,B,C); two 32-ounce jars of sediment from each grab.

Station 5 — Water depth = ? (see (USGS records)
Three grabs (A,B,C); two 32-ounce jars of sediment from each grab.

Station 6 — Water depth = 85 meters
One grab (A); two 32-ounce jars of sediment. Grab broke and no more grabs were taken at this station.

Station 13 — Water depth = 40 meters
Three grabs (A,B,C); two 32-ounce jars of sediment from each grab.

Station 14 — Water depth = 42 meters
Three grabs (A,B,C); two 32-ounce jars of sediment from each grab.

Station 3 — Grab C -- 1 clam in grab removed and stored separately.

NOTE: At stations 13 and 14 tar lumps were noted at surface. No obvious tar on grab sample or near it coming out of water into the water. However, it was dark and visibility was limited.

Water samples for oil analyses
R/V *Oceanus* Cruise 19

Sample	Depth of sample (meters)	Water depth (meters)	Extracted sea water volume	Notes[b]
Station 1				
Surface-total	0	81-82	3040 ml	1.
Surface-filtered	0		3150 ml	1.
Mid-depth-total	50		2475 ml	1.
Mid-depth-filtered	50		3140 ml	1.
Bottom-total	91		2905 ml	1.
Bottom-filtered	91		3055 ml	1.
Station 2				
Surface-total	0		Saved for extraction effic. test	2.
Surface-filtered	0		"	2.
Mid-depth-total	74		"	2.
Mid-depth-filtered	74		"	2.
Bottom-total	144		"	2.
Bottom-filtered	144		3040 ml	3.
Station 3				
Surface-total	0	140	Saved for extraction effic. test	2.
Surface-filtered	0		"	2.
Mid-depth-total	100		"	2.
Mid-depth-filtered	100		"	2.
Bottom-total	150		"	2.

Blanks #1, #2, #3

100 ml CH_2Cl_2 in 32 oz. jar with aluminum foil between cap and glass jar. 100 ml CH_2Cl_2 was poured into 1-gallon glass jugs, shaken as if sample was present and poured off to the mason jars.

Water samples for oil analyses (continued)
R/V *Oceanus* Cruise 20

Sample	Depth of sample[a] (meters)	Water depth (meters)	Extracted sea water volume	Notes[b]
<u>Station 1</u>				
Surface-total	0	21.5	3625 ml	4.
Surface-filtered	0		Saved for extraction effic. test	2.
Mid-depth-total	10		3625 ml	4.
Mid-depth-filtered	10		2410 ml	4.
Bottom-total	21.5		Saved for extraction effic. test	
Bottom-filtered	21.5		2675 ml	4.
<u>Station 2</u>				
Surface-total	0	28	3000 ml	4.,5.
Surface-filtered	0		2882 ml	4.
Mid-depth-total	10		3360 ml	4.
Mid-depth filtered	10		3077 ml	4.
Bottom-total	26		3376 ml	4.
Bottom-filtered	26		2655 ml	4.
<u>Station 3</u>				
Surface-total	0		3438 ml	4.
Mid-depth-total	25		3170 ml	4.
Bottom-total	37		3420 ml	4.
<u>Station 4</u>				
Surface-total	0		3500 ml	4.
Mid-depth-total	20		3865 ml	4.
Bottom-total	44		3550 ml	4.
Bottom-filtered	44		3045 ml	4.
<u>Station 5</u>				
Surface	Sample missed due to G/O bottle pre-trip			
Mid-depth-total	40		2965 ml	4.
Bottom-total	65		3600 ml	4.

Water samples for oil analysis (continued)
R/V *Oceanus* Cruise 20

Sample	Depth of sample (meters)	Water depth (meters)	Extracted sea water volume	Notes[b]
Station 6				
Surface-total	0	85	3525 ml	4.
Mid-depth-total	60		3220 ml	4.
Mid-depth-filtered	60		3160 ml	4.
Bottom-total	84		3635 ml	4.
Bottom-filtered	84		3135 ml	4.
Station 13				
Surface-total	0	40	3015 ml	4.
Mid-depth-total	20		2975 ml	4.
Bottom-total	40		3350 ml	4.
Station 14				
Surface-total	0	42	Saved for extraction effic. test	
Surface-filtered	0			
Mid-depth-total	20			
Bottom-total	40			
Bottom-filtered	40			

Blank #1

100 ml CH_2Cl_2 rinse of gallon jug after use for surface sample *Oceanus* 20/1 surface total.

a. See USGC sampling log sheet (see next page). Discrepancies in depth due to wire angle, which can be corrected for by calculations using rosette-transmissometer at USGS, Woods Hole, Massachusetts

b. 1. Stored in 16 oz. glass mason jars.
2. Stored as water sample over CH_2Cl_2 in one-gallon brown glass bottle and saved for extraction efficiency test.
3. Stored in 32 oz. glass mason jars.
4. Stored in 8 oz. glass jars.
5. Surface sample had suspended particulates visible in it as fine dispersion even after shaking with CH_2Cl_2 and settling time of 30 minutes.

Samples collected on R/V *Oceanus* cruises 19 and 20

(Courtesy of USGS and John Milliman, WHOI)

Date 1977	Cruise	Station No.	Transmissometer tape No.	Time (min)	Latitude(N) deg	Latitude(N) min	Longitude(W) deg	Longitude(W) min	Water depth (m)	Sample depth 1	Sample depth 2	Sample depth 3	LORAN-C
2/20	19	1	1	35	41	23.969	68	34.878	81-82	0	50	91	
2/21	19	2	1	45	41	24.9	68	46.2	125	0	74	144	
2/21	19	3	2		41	25.7	68	55.3	140	0	100	150	
2/28	20	1	1	30	41	10.095	70	12.647	21.5	0	10	21.5	
2/28	20	2	1	20	41	2.2	70	13.6	28	0	10	26	37986.8 70030.9
2/28	20	3	1	25	40	52.2	70	12.8	38	0	25	37	38056.0 70076.6
2/28	20	4	2	20	40	41.5	70	13.1		0	20	44	38135.8 70123.1
2/28	20	5	2	30	40	30.8	70	12.8			40	65	38220.8 70175.3
2/28	20	6	3		40	20.5	70	12.1	85	0	60	84	38290.2 70220.9
2/28	20	13	3		40	59.3	69	35.7	40	0	20	38	37725 20092.8
2/29	20	14	3		41	2.4	69	35.7	42	0	20	40	37705.3 70079.6

USCGC *VIGILANT* CRUISE
DECEMBER 24-25, 1976

Elaine Chan, of the NOAA/USCG SOR team, was lowered to the USCGC *Vigilant* from an H-3 helicopter on December 24, 1976. Ms. Chan brought Sterile Bag Samplers and sampling bags, and instructed the Commanding Officer, Cmdr. I. Cruikshank, and the MSO in the operation of the samplers. From 1245 that day until 0845 on Christmas Day, personnel from the *Vigilant* obtained 24 water samples. The samples were taken in pairs, one each at approximately 1 to 2 feet below the surface, and the other at about 10 feet below the surface. At 0900 on December 25, 1976, all 24 samples were flown by helicopter to the Coast Guard Cape Cod Air station. With the exception of two samples, which were intercepted by USCG legal personnel, the samples were picked up by NOAA personnel and kept in frozen storage until transported to the USCG R&D Center in Groton, Connecticut, for analysis.

The sampling stations (two samples per station) are listed below.

Station	Latitude (N)		Longitude (W)			
No.	deg	min	deg	min	Date	Time
1	41	01.3	69	22.0	12/24/76	1245
2	41	01.5	69	24.3	12/24/76	1355
3	41	01.4	69	25.8	12/24/76	1418
4	41	01.4	69	26.1	12/24/76	1432
5	41	00.0	69	25.5	12/24/76	1456
6	40	58.5	69	24.0	12/24/76	1520
7	41	01.6	69	28.6	12/24/76	1735
8	41	01.8	69	29.7	12/24/76	1800
9	41	03.0	69	34.0	12/24/76	1845
10	41	02.0	69	27.7	12/25/76	0708
11	41	01.3	69	27.0	12/25/76	0800
12	41	01.9	69	26.3	12/25/76	0845

USCGC *EVERGREEN* CRUISE
DECEMBER 22-28, 1976

The USCG R&D Center's research vessel *Evergreen* proceeded to the area covered by the *Argo Merchant* oil slick on December 22, 1976. Sediment samples and bottom photographs were taken at five stations in order to evaluate the potential for bottom contamination, and 20 water samples were taken using Sterile Bag Samplers. These samples were all analyzed by the common analytical network established at the January 3-4, 1977, meeting at Woods Hole.

Station locations and other information are given below.

Station No.	Latitude (N) deg	min	Longitude (W) deg	min	No. water samples	No. sediment samples	No. bottom photos
A	41	7.0	69	56.0	4	4	1
B	40	52.0	69	35.0	4	4	1
C	40	58.0	69	08.0	4	4	1
D	40	45.0	68	25.0	4	4	1
E	40	55.0	67	56.0	4	4	0

WHITEFOOT CRUISE
DECEMBER 28-29, 1976

Under the direction of B. Butman of USGS, the charter vessel *Whitefoot*, in addition to participating in the emplacement of the current meters described in Section 2, obtained three sediment samples using a Van Veen grab. These samples were sent to the USCG R&D Center for analysis. The sample locations are given below.

Station No.	Latitude (N) deg	Latitude (N) min	Longitude (W) deg	Longitude (W) min	No. sediment samples
1	40	59.0	69	59.0	1
2	40	58.0	69	29.0	1
3	40	56.5	69	26.0	1

USCGC *BITTERSWEET* CRUISE
DECEMBER 29, 1976

Prior to relieving the USCGC *Vigilant* on-scene at the *Argo Merchant* wreck, LCDR Overath, Commanding Officer of the *Bittersweet*, was briefed by Elaine Chan in the operation of Sterile Bag Samplers. On December 29, 1976, LCDR Bebeau of the *Bittersweet* obtained 10 water samples in the vicinity of the wreck. Two samples were taken at each of five stations; one sample at a depth of approximately one times the wave height, the other at a depth equal to twice the wave height. These samples were flown to Cape Cod by helicopter, and kept frozen until analyzed at the USCG R&D Center. Sample stations and depths are given below.

Station No.	Latitude (N) deg	Latitude (N) min	Longitude (W) deg	Longitude (W) min	Depths ft
1	41	01.3	69	28.7	5/10
2	41	00.5	69	30.5	6/12
3	41	01.4	69	30.0	6/12
4	41	03.0	69	28.0	6/12
5	41	03.5	69	29.9	4/8

DELAWARE II CRUISE DE 76-13
DECEMBER 22-24, 1976

The NOAA ship *Delaware II* sailed from Woods Hole, Massachusetts, on December 22, 1976, to the vicinity of the oil spill from the *Argo Merchant*, aground on Fishing Rip, and returned to Sandy Hook, New Jersey, on December 24, 1976.

Scientific Personnel

Northeast Fisheries Center, NMFS, Woods Hole, Massachusetts

Henry Jensen, Chief of Party
Peter Gibb
Rhett Lewis
Gordon Waring
Paul Loiseau
Frank Almedia

Northeast Fisheries Center, NMFS, Narragansett, Rhode Island

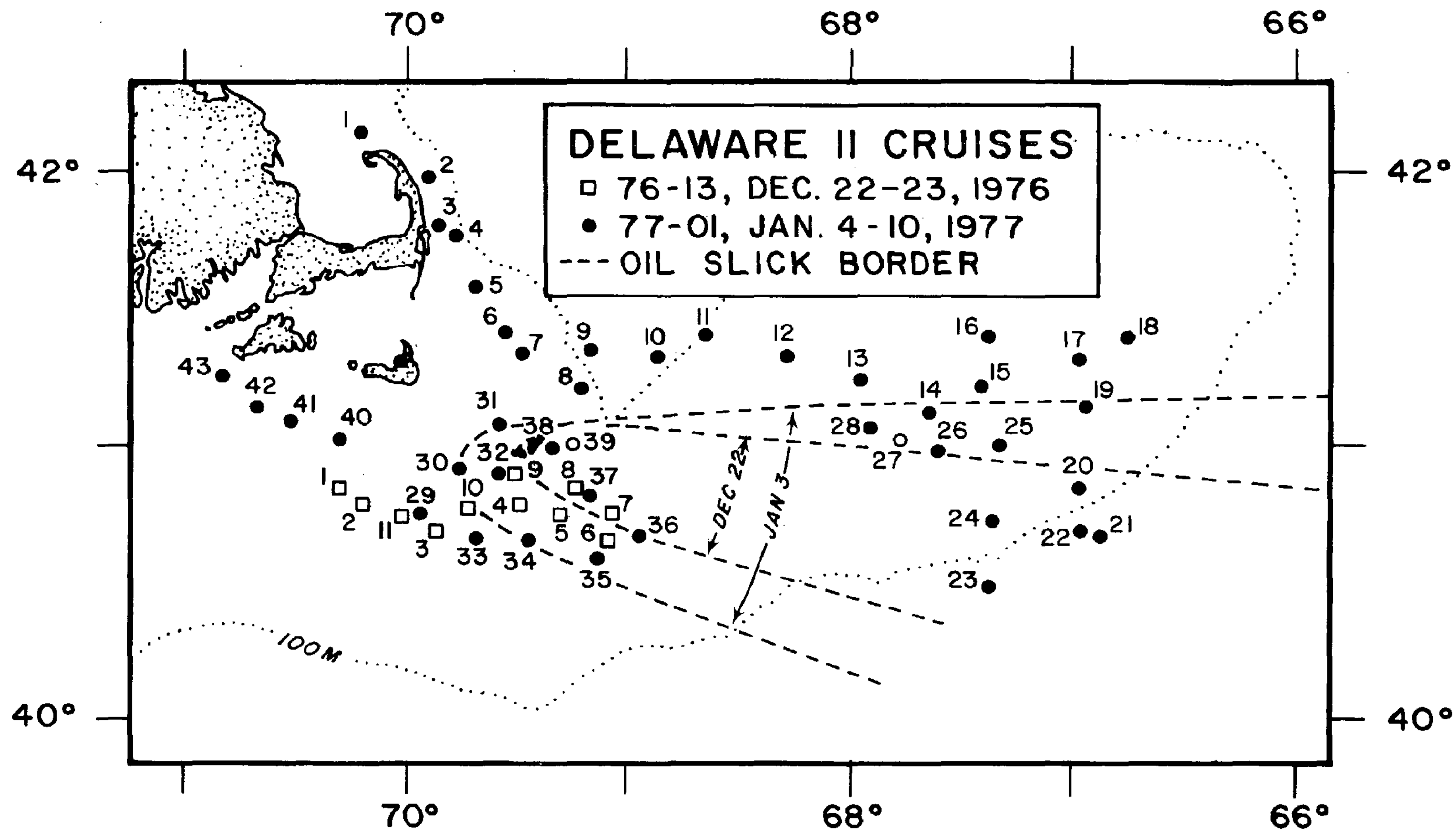
Ron Boisvert
Gary Carter
Joe Kane
Kevin McCarthy

Objectives

The objectives of the cruise were to sample the fish and associated invertebrate and plankton populations in the vicinity of the oil spill, and to obtain samples of fish from outside the area of the oil slick to be used as controls for fish to be caught later in the same area. Additional objectives were to obtain oil, water, and sediment samples and to observe any obvious effects of oil on birds and mammals in the area.

Operations

The cruise was conducted as scheduled. Eleven stations, shown in the accompanying figure, were completed; six were occupied with miscellaneous gear, and four with bathythermograph drops and surface water samples only. Station positions were occupied at the boundary of the slick as reported by the U.S. Coast Guard, who made aerial observations on the day of departure. Three gear stations were occupied on each side of the southern border of the slick. The surface of the water at station 9 (one of three stations located within the slick) was not covered with oil at the time it was occupied. Plankton, hydrographic, XBT, and sediment samples were obtained from both inside and outside the slick. Two trawl stations were made outside the slick to obtain fish without contamination from floating oil for miscellaneous studies. All data were recorded in Eastern Standard Time unless otherwise


DELAWARE II CRUISES
76-13, DEC. 22-23, 1976
77-01, JAN. 4-10, 1977
OIL SLICK BORDER
DEC 22
JAN 3
100M
70°
68°
66°
42°
40°

noted. General information on the various gear, samples, and observations is given below, including preliminary on-ship observations regarding the impact, if any, of the oil. Type of samples, data disposition, and other detailed information is contained in the report on the second *Delaware II* cruise, DE 77-01.

Observations

Water temperature profile. Stations: 1-11. Disposition of data: Woods Hole. XBT probes were dropped at each station prior to other sampling. Temperatures were nearly isothermal between 5°C in the shoals and 7°C in deeper waters.

Meteorological Observations. Stations: 1-11. Disposition of data: Woods Hole. Observations (wind speed, barometric pressure, temperature, wave height, etc.) were taken at all stations. Wind speed ranged from 12 to 27 knots; wave height, between 3 and 6 feet.

Surface water samples. Stations: 1-11. Disposition of samples: Woods Hole. Samples taken at every station. There was noticeable oil on the surface at stations 7 and 8, although oil was not apparent in samples. A surface oil sample was taken at station 7, where the oil contained sand.

Oil slick observations. Stations: 1-11. Disposition of data: Woods Hole. Oil was found at stations 7 through 8, and halfway to station 9 in 5- to 20-foot wide patches occurring in rows from northwest to southeast. The oil resembled floating black cloth, wrinkled from wave action. Other and more general observations (95 to 99% of this area) were the thin, greasy sheen with characteristic prismatic phenomena and the odor, which was noticeable but not outstanding.

Fish samples. Stations: 4 and 6. Disposition of samples: Woods Hole. A 15-minute tow at 3.5 knots using a Yankee #36 trawl without rollers and with a 1/2-inch liner was made at both stations. All species were sorted, identified, and measured (fork length) where applicable. Approximately 20 species of fish and 10 invertebrates were taken. An oil streak 1 by 2 inches was noticed on a winter flounder at station 4. All other specimens appeared oil-free.

Hydrocarbon samples. Stations: 4 and 6. Disposition of samples: Woods Hole. Approximately 20 species of fish and 10 species of invertebrates were frozen in foil-lined bags for hydrocarbon analysis.

Stomach analysis. Stations: 4 and 6. Disposition of samples. Woods Hole. Stomachs from little skate, big skate, spiny dogfish, cod, windowpane, and ocean pout were preserved in 10% formalin for food chain contamination studies.

Maturation. Stations: 4 and 6. Disposition of data: Woods Hole. Gonad development was observed and logged on standard maturation forms; no fish were spawning. Various stages of ripening were observed in cod, long-horned sculpin, and ocean pout.

Sonar Traces. Stations: 4 and 6. Disposition of traces: Woods Hole. The 20- to 25-foot sand humps shown on the bottom trace of station 4 are typical of the bottom on Nantucket shoals at a depth of 30 fathoms or less; the relatively flat though rough bottom trace of station 6 is typical of the channel area at 30 fathoms and greater.

Water column samples. Stations: 4, 5, 7, and 8. Disposition of samples: Sandy Hook. The water bag sampler was used to collect water at 5 meters below surface and 5 meters above bottom at stations 4, 5, and 7. At station 8, the samples were collected at 5 and 15 meters below surface. Oil was not observed in any of these samples.

Water column plankton samples. Stations: 4-9. Disposition of samples: Narragansett. Bottom to surface bongo tows were made (20 and 61 centimeter bongos) with 0.165, 0.253, 0.333, and 0.505 millimeter mesh nets. No oil particles were noticed but there was probably surface oil contamination in samples 8 and 9 from stations 7 and 8.

Surface plankton samples. Stations: 4-9. Disposition of samples: Narragansett. Neuston samples (using 0.505-millimeter mesh) showed specks of tar at stations 4, 5, 6, and 9; station 9 was possibly contaminated. Stations 7 and 8 were made in the oil slick and the net soaked with oil was saved in a can. Larval sand launce and hake were observed in the samples, and Sagitta (arrow worms) comprised a large portion of the sample. Also, eggs were observed in the station 9 sample.

Bottom biological samples. Stations: 4 and 6. Disposition of samples: Woods Hole. A 25-centimeter ring net (mesh approximately 1 millimeter) attached to the trawl headrope was used at trawl stations to sample smaller organisms that escape the trawl. Catch was largely small crustacea, which were preserved in 10% formalin.

Bottom sediment samples. Stations: 4-9. Disposition of samples: Woods Hole. Sediments obtained at station 4 by 4-inch pipe dredge were found to be clean; at station 5 by bongos hitting bottom, were discarded, but noted to be clean; at station 6 by pipe dredge were clean; at station 7 by bongos were clean; at station 8 in small amounts, by Dietz Lafond grab, were clean; and at station 9 using a Digby dredge contained shell fragments and were also found to be clean. All sediments were stored dry.

Live samples. Station: 9. Disposition of samples: Milford. Approximately 20 hermit crabs, clams, and miscellaneous bivalves were secured using a Digby dredge (small 2-foot wide dredge with ring bag and 1/2-inch liner). A tow was made for 5 minutes at approximately 2-1/2 knots. Live samples were maintained in running water. Specimens reached Sandy Hook in viable condition.

Vessels. No fishing vessels were sighted, probably due to the holiday season. The *Argo Merchant* was observed at approximately 6 miles distance. There were two Coast Guard vessels in the area, and two helicopters.

DELAWARE II CRUISE DE 77-01
JANUARY 4-10, 1977

The NOAA R/V *Delaware II* sailed from Woods Hole, Massachusetts, on January 4, 1977, and returned to Woods Hole on January 10, 1977. The area of investigation was bounded on the north and west by latitude 41°30'N and longitude 70°00'W, and extended to the 150-fathom depth contour on the south and east. This area was chosen to include clean zones for control stations on all sides of the estimated oil slicks's route. The oil slick was determined by extending the boundary route of the available sightings as of January 3. Additional stations were made east of Cape Cod and south of Nantucket Shoals for the release of seabed drifters and additional control stations.

Scientific Personnel

Northeast Fisheries Center, NMFS, Woods Hole, Massachusetts

Henry Jensen, Chief Scientist
John Nicolas
Linda Despres
Eva Montiero

Northeast Fisheries Center, NMFS, Sandy Hook, New Jersey

John Ziskowski

Northeast Fisheries Center, NMFS, Milford, Connecticut

Randy Goodlet

Northeast Fisheries Center, NMFS, Narragansett, Rhode Island

Joseph Kane
Loretta Sullivan

Manomet Bird Observatory, Manomet, Massachusetts

Graig Scharf

Objectives

The purpose of the cruise was to assess the condition of the fish stocks and associated populations of invertebrates and plankton on the portions of Nantucket Shoals and Georges Bank through which the oil from the tanker *Argo Merchant* had drifted. An additional objective was to obtain oil, water, and sediment samples, and to observe the oil's effect on birds and mammals of the area.

Delaware II station data

Delaware II - 76-13

Station	Day	Date Month	Year	Time (EST)	Latitude	Longitude	Depth 1/ (M)	Wind Dir	Wind Sp	Wave Hgt (FT)	Air Temp (°C)	Surf 1/ Temp (°C)	Bot 1/ Temp (°C)
1	22	12	76	1930	40°52'	70°20'	43	27	14	6	2.2	6.6	6.6
2	22	12	76	2000	40°49'	70°13'	41	27	14	6	2.2	6.5	6.8
3	22	12	76	2130	40°43'	69°53'	44	23	14	6	3.3	4.7	4.8
4	22	12	76	2328	40°49'	69°30'	44	24	18	6	4.4	5.7	5.7
5	23	12	76	0209	40°47'	69°18'	50	23	14	4	5.6	6.3	6.3
6	23	12	76	0317	40°43'	69°05'	84	24	15	4	6.7	6.7	6.8
7	23	12	76	0651	40°48'	69°04'	79	12	8	2	6.7	7.0	7.9
8	23	12	76	0904	40°52'	69°14'	61	12	2	3	7.2	7.0	-
9	23	12	76	1219	40°56'	69°30'	44	18	6	3	8.3	6.1	6.1
10	23	12	76	1415	40°50'	69°44'	31	27	8	4	6.1	5.0	5.0
11	23	12	76	1520	40°46'	70°03'	39	27	5	4	6.1	5.0	5.6

Delaware II - 77-01

Station	Day	Date Month	Year	Time (EST)	Latitude	Longitude	Depth 1/ (M)	Wind Dir	Wind Sp	Wave Hgt (FT)	Air Temp (°C)	Surf 1/ Temp (°C)	Bot 1/ Temp (°C)
1	4	01	77	1958	42°07'	70°13'	59	32	25	2	2.2	3.2	3.8
2	4	01	77	2143	42°00'	69°57'	40	32	24	3	3.3	3.9	4.0
3	4	01	77	2345	41°49'	69°52'	46	32	25	4	3.3	4.0	4.7
4	5	01	77	0135	41°48'	69°50'	75	34	25	4	2.8	4.2	5.3
5	5	01	77	0415	41°37'	69°43'	40	36	26	4	3.9	4.6	4.7
6	5	01	77	0610	41°27'	69°34'	30	34	25	5	3.3	4.7	5.2
7	5	01	77	0835	41°22'	69°30'	32	36	24	5	2.8	4.7	4.7
8	5	01	77	1115	41°14'	69°13'	84	34	20	4	3.3	6.5	6.5
9	5	01	77	1330	41°23'	69°10'	144	36	15	5	3.9	6.6	7.1
10	5	01	77	1608	41°22'	68°51'	126	36	14	4	4.4	6.7	7.1
11	5	01	77	1800	41°27'	68°39'	96	33	8	4	3.3	6.6	6.8
12	5	01	77	2112	41°22'	68°15'	50	32	15	2	3.3	5.4	5.8
13	5	01	77	2340	41°17'	67°57'	35	32	10	2	2.8	5.5	6.1
14	6	01	77	0105	41°10'	67°38'	51	34	10	3	4.4	5.4	6.4
15	6	01	77	0250	41°15'	67°24'	49	35	16	3	3.9	5.7	5.8
16	6	01	77	0450	41°26'	67°22'	44	36	14	4	4.4	6.0	6.1
17	6	01	77	0737	41°21'	66°57'	66	03	20	4	3.9	5.9	5.9
18	6	01	77	0945	41°27'	66°42'	66	01	20	3	2.8	6.3	6.5
19	6	01	77	1215	41°10'	66°55'	70	03	17	4	3.9	6.1	5.8
20	6	01	77	1420	40°53'	66°58'	89	03	16	4	4.4	7.7	6.7
21	6	01	77	1610	40°42'	66°51'	220	03	12	4	2.8	7.1	8.7
22	6	01	77	1742	40°43'	66°57'	143	05	10	4	2.2	8.4	9.1
23	6	01	77	2100	40°31'	67°21'	143	05	8	1	2.2	6.8	10.3
24	6	01	77	2333	40°45'	67°21'	97	36	-	2	2.2	6.7	6.9
25	7	01	77	0150	41°02'	67°19'	68	13	5	2	2.8	6.2	5.9
26	7	01	77	0335	41°01'	67°35'	64	11	12	2	2.8	5.3	5.7
27	7	01	77	0505	41°04'	67°45'	54	10	8	2	3.9	5.3	6.1
28	7	01	77	0623	41°06'	67°53'	49	10	20	3	5.0	5.1	5.2
29	8	01	77	2037	40°46'	69°57'	26	32	18	4	0.6	4.1	4.1
30	8	01	77	2233	40°56'	69°46'	35	32	16	4	-2.2	4.1	4.5
31	8	01	77	2353	41°06'	69°36'	31	31	18	4	-2.2	5.4	5.4
32	9	01	77	0153	40°56'	69°34'	39	31	20	4	-1.7	4.7	4.9
33	9	01	77	0405	40°41'	69°41'	52	30	18	4	-2.2	5.4	5.4
34	9	01	77	0618	40°40'	69°26'	53	29	20	4	1.7	5.7	5.7
35	9	01	77	0833	40°37'	69°08'	72	32	16	4	0.0	6.5	6.5
36	9	01	77	1030	40°42'	68°56'	67	29	20	4	0.0	5.9	5.9
37	9	01	77	1300	40°51'	69°10'	63	31	16	4	-1.1	5.4	5.5
38	9	01	77	1415	41°01'	69°19'	58	32	12	4	-1.1	5.7	5.8
39	9	01	77	1530	41°02'	69°15'	56	32	6	4	-1.1	6.3	6.3
40	9	01	77	2000	41°03'	70°20'	27	29	9	4	-2.2	1.6	2.0
41	9	01	77	2100	41°06'	70°33'	42	27	8	1	-2.2	4.0	4.0
42	9	01	77	2200	41°09'	70°43'	37	90	8	1	-1.1	4.0	4.0
43	9	01	77	2300	41°16'	70°52'	24	07	16	1	-1.7	2.1	2.1

1/ Depth, surface and bottom temperature as recorded from XBT Trace

Samples taken on *Delaware II* cruises 76-13 and 77-01

SAMPLE	TYPE OF SAMPLE	SAMPLER	SHIP'S SPEED	TIME	AREA SAMPLED	NO. STA	NO. SAMP	CONTAINER	METHOD PRESERV	INITIAL NMFS DISPOSITION	PAGE
STATION DATA											
Water temp	Temp/depth	XBT	Stopped	-	Water col	54	54	-	XBT trace	Woods Hole	4
BOTTOM CURRENT											
Drifters	Current	Seabed drifter	-	-	Bottom	43	41	-	-	Woods Hole	5
PLANKTON											
Surf plankton	Plankton	.5x1m Neuston	2-4 knots	10 min	Surface	44	44	Qt jar	Formalin	Narragansett	6
Water col plankton	Plankton	61 cm .505 Bongo	2-3 knots	5-12 min	≤110 fm	39	36	"	"	"	6
		61 cm .333 Bongo	"	"	"	39	36	"	"	"	6
		20 cm .253 Bongo	"	"	"	22	22	"	"	"	6
		20 cm .165 Bongo	"	"	"	22	20	"	"	"	6
Benthic plankton		30 cm 1.0 Ring net	3.5 knots	15 min	Bottom	26	21	"	"	Woods Hole	6
HYDRO SAMPLES											
Hydro (surface)	Chlorophyll	5.0 liter Nisken bottle	3.5 knots	-	1 m below	15	11	Milli filter	Frozen	Narragansett	7
"	Nutrients	"	"	-	"	15	13	125 ml	"	"	7
(mid)	Chlorophyll	"	"	-	Mid-depth	15	13	Milli filter	"	"	7
"	Nutrients	"	"	-	"	15	15	125 ml	"	"	7
(bottom)	Chlorophyll	"	"	-	1 m above	2	1	Milli filter	"	"	7
"	Nutrients	"	"	-	"	2	2	125 ml	"	"	7
Sterile Hydro (surface)	Hydrocarbon	2.0 liter Nisken bag	Stopped	-	5 m below	4	4	Sterile Plastic bag	"	Woods Hole	8
(bottom)	"		"	-	5 m above	4	4	"	"	"	8
Surface water	Salinity	Bucket	Variable	-	Surface	54	54	125 ml	-	"	8
SEDIMENT SAMPLES											
Benthic sediments	(Unsorted) Sediment	9 cm Pipe dredge	3.5 knots	15 min	Bottom	23	17	Qt jar	Air dry	Woods Hole	8
	(Sorted) Sediment	Digby dredge	2.0 knots	10 min	"	10	9	"	"	"	8
BIOLOGICAL SAMPLES											
Trawl[1/]	*Flesh	#36 Yankee	3.5 knots	15 min	Bottom	26	86	Foil	Frozen	Woods Hole	9,10-14
Fish	Pathology	"	"	"	"	26	21	Glass jar	Formalin	Oxford	9,10-14
	Biochemistry	"	"	"	"	26	14	Plastic bag	Frozen	Milford	9,10-14
[1/]25m sweep 13 mm liner	Stomachs	"	"	"	"	26	40	Qt jar	Formalin	Woods Hole	9,10-14
	Maturity	"	"	"	"	26	39	-	Mat. log	"	9,10-14
	Behavior	"	"	"	"	26	1	Live tank	Live	"	9,10-14
Trawl	Benthic	Yankee	3.5 knots	15 min	Bottom	26	3	Qt jar	Formalin	Woods Hole	8,9,15-18
Invertebrates	*Flesh	"	"	"	"	26	26	Foil	Frozen	"	8,9,15-18
	Pathology	"	"	"	"	26	28	Glass jar	Formalin	Oxford	8,9,15-18
	Biochemistry	"	"	"	"	26	18	Plastic bag	Frozen	Milford	8,9,15-18
	Behavior	"	"	"	"	26	3	Live tank	Live	Woods Hole & Milford	8,9,15-18
Dredge[2/]	Benthic	Digby dredge	2.0 knots	10 min	Bottom	10	9	Qt jar	Formalin	Woods Hole	8,9,15-18
Invertebrates	*Flesh	"	"	"	"	10	7	Foil	Frozen	"	8,9,15-18
	Pathology	"	"	"	"	10	13	Glass jar	Formalin	Oxford	8,9,15-18
[2/]75x22 cm 13mm liner	Biochemistry	"	"	"	"	10	2	Plastic bag	Frozen	Milford	8,9,15-18
	Behavior	"	"	"	"	10	3	Live tank	Live	Woods Hole & Milford	8,9,15-18
Miscellaneous	Benthic	9 cm Pipe dredge	3.5 knots	15 min	Bottom	26	1	Qt jar	Formalin	Woods Hole	8
Invertebrates	"	0.5 liter grab Dietz-Lafond	Stopped	-	"	1	1	"	"	"	8
	"	Plankton	Variable	(hit bottom)	"	1	1	"	"	"	8

*Whole specimens to be used primarily for hydrocarbon analysis

Operations

The cruise, originally scheduled for 10 days, was reduced by storms to 4 working days. All stations were preselected randomly. The stations on the northern side of the slick boundary were given priority for use as controls and also for establishing the present limits of any contamination. The stations on the eastern limits of the bank and the stations in the area of initial impact around Nantucket shoals were also completed. The southern and mid-sections of the sampling area were omitted.

Forty-three stations were completed. XBT and surface bucket thermometer for temperature and salinity samples were used at every station. Five seabed drifters were released at each station, except stations 27 and 39. The #36 Yankee trawl, with a ring net and pipe dredge attached, was used at 24 stations. The Digby dredge was used at nine stations. At six of the trawl stations and at all the Digby stations, a hydrocast was made. Neuston plankton gear was used through station 38. The 61-centimeter bongos were used through station 39, while the 20-centimeter bongos were used in the western part of the study area only (stations 1-11 and 29-39).

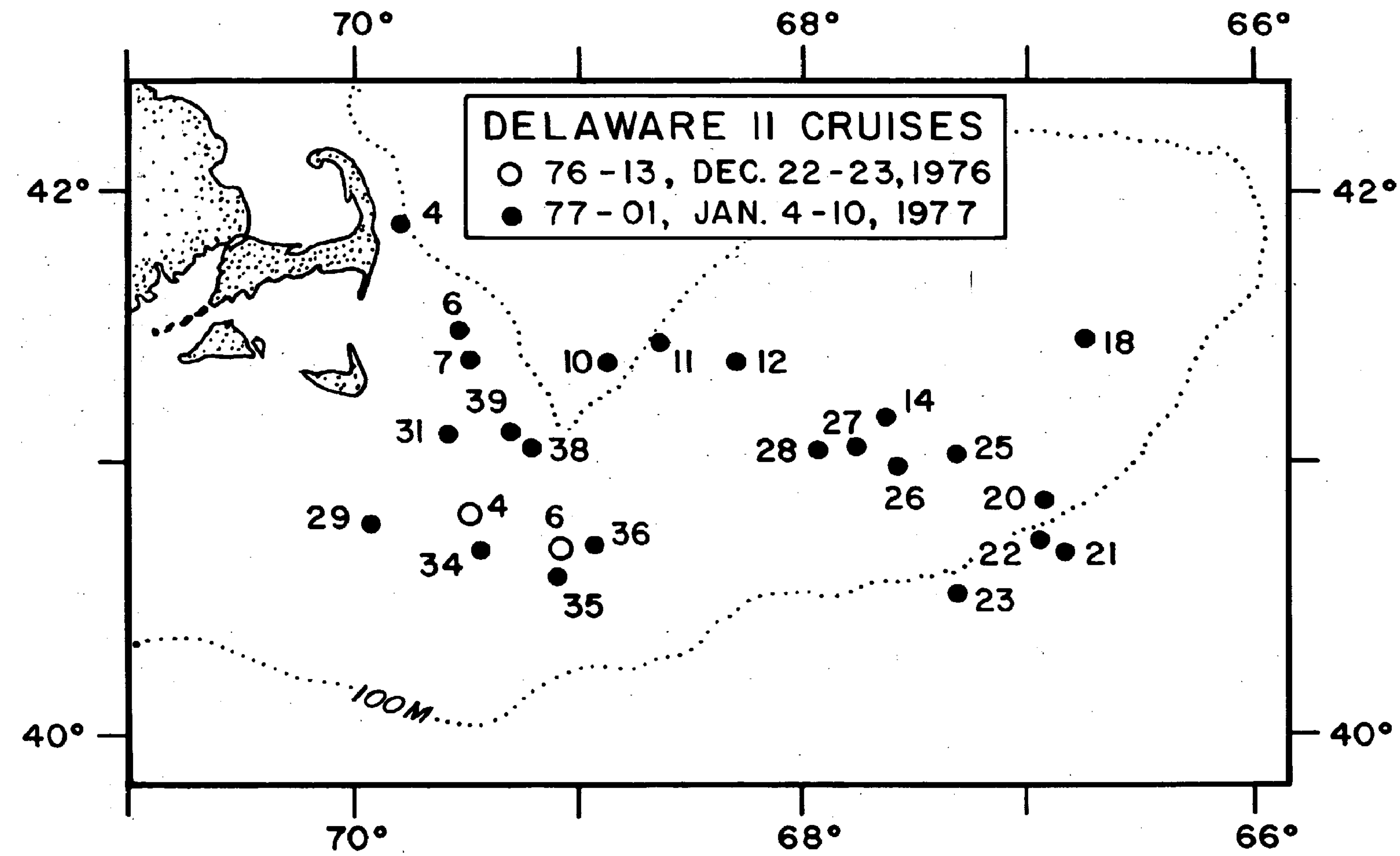
The general information on these samplers, their use, and the information on the samples taken, is presented in tabular form. This includes information on the samples taken during both *Delaware II* cruises: 76-13, December 22-23; and 77-01, January 4-10. Also provided is information concerning the types of samples, station plots, data disposition, and the like.

Bird, Mammal, and oil slick observations were made by an observer from the Manomet Bird Observatory and other scientists aboard the *Delaware II*. Oil samples from the engine fuel, the winch hydraulic system, the side of the vessel, and from the oil slick were taken (disposition: Woods Hole). All data were recorded in Eastern Standard Time unless otherwise noted.

Results

Preliminary on-ship observations showed clean fish, sediment, and water throughout the area surveyed, except at stations 37-39, which were in the vicinity of the wreck and showed some oil (estimated at less than 0.1%) on the surface. All samples await detailed examination.

R. Wigley of the NMFS Northeast Fisheries Center, Woods Hole, collected samples of surficial bottom sediments from the R/V *Delaware II* during two cruises conducted shortly after the *Argo Merchant* grounding. The first samples were collected in December 1976 at two stations, 4 and 6, on cruise 76-13. In early January 1977, a series of 23 samples was collected on cruise 77-01. The location of each sample is plotted in the accompanying figure. The samples were collected by means of a pipe dredge and a Digby dredge. Samples were stored in glass containers; sediment volume ranged from approximately 50 to 750 cubic centimeters. Each sample was analyzed microscopically for tar-balls or other evidence of the presence of oil or oil-like substances. Dominant components of the sediments were found to be sand,



Locations of bottom sediment samples collected by R. Wigley, NMFS, on *Delaware II* cruises 76-13 and 77-01.

pebbles, and mollusk shell fragements. These components, plus some of the less common items, are listed for each station in the table below.

No evidence of any oil-like substance was detected in any of the samples. Through arrangements made by G. Kelly, NMFS, and G. Heimerdinger, EDS, these samples were then forwarded to the USCG Research and Development Center, Groton, Connecticut, for screening.

Surficial bottom sediments collected on *Delaware II* cruises
by R. Wigley, NMFS

Station	Gear	Remarks
		Cruise 77-01 (23 Samples)
4	Digby dredge	Arctia shell and worm tubes.
6	Pipe dredge	Coarse brown sand.
7	"	Coarse brown sand.
10	"	Medium to fine sand with silt-clay.
11	"	Coarse sand. Slight amount of silt-clay.
12	"	Coarse sand, clean, pale brown.
14	"	Fine sand, light gray.
18	"	Medium sand, medium brown. Slight amount of silt-clay.
20	Digby dredge	Shell fragments 1/4 to 5 centimeters, and black rock about 5 by 7 centimeters. Venericardia, Astarte, Arctica, Onuphis.
21	Pipe dredge	Medium to coarse sand, medium brown.
22	Digby dredge	Shells and skate egg. Astarte, Apporhais, Arctica, Dentalium Placopecten. Some live.
23	Pipe dredge	Medium-fine sand, greenish brown. Small amount silt-clay.
25	Digby dredge	Large shells. Arctica, Colus stimpsoni, Lunatia heros, Placopecten. Clinker 5 by 7-1/2 centimeters. Crangon-decaying.
26	"	Large shells. Arctica, Buccinum, Balanus crenatus, Echinarachnius. Trace of fine sand. Pagurus acadianus.

Surficial bottom sediments collected on *Delaware II* cruises by R. Wigley, NMFS (continued)

Station	Gear	Remarks
		Cruise 77-01
29	Pipe dredge	Fine sand, light gray.
31	"	Medium sand 15% small mollusk fragments, pale brown.
34	Digby dredge	Two Arctica shells 5 to 10 centimeters. One Echinarachnius 1-1/4 centimeters.
35	"	Coarse sand, brown. Small (1/4 to 1 centimeter) pebbles, brown. Shells Placopecten. Hydroids.
36	Pipe dredge	Medium-coarse sand. Few small (1/8 to 1 centimeters) pebbles, medium-brown.
38	"	Pebbles (1/8 to 3-1/2 centimeter), black to white. Sand, wide range in size, black to white. Mollusk shell fragements, 3%.
39	Digby dredge	Pebbles (1/8 to 6 centimeters) white to black. Coarse-medium sand, brown-white to black. Shells. Venericardia, Spisula, Placopeten. Stronglylocentrotus, fresh dead, 7 millimeter in diameter. Amaroucium ?, 2 pieces 5 to 10 centimeters.
		Cruise 76-13 (2 Samples)
4	Pipe dredge	Medium-fine sand, pale brown, Echinarachnius shell fragments, well rounded.
6	"	Medium-fine sand, pale brown. < 1% shell fragments. 1 to 2 pebbles, 1 to 10 millimeters.
27	Pipe dredge	Fine sand, light gray.
28	Digby dredge	Shell fragements 1/2 to 5 centimeters, white, clean. Crepidula fornicata, Echinarachnius. Crassotrea, Nassarius trivittatus. Small (1/2 centimeter) pebbles. Anomia, Spisula Ensis, Astarte.

R/V *ENDEAVOR* CRUISE EN-002
DECEMBER 28-30, 1976

Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

The R/V *Endeavor* departed Quonset, Rhode Island, at 1800 on December 28, 1976, and returned to Quonset at 1900 on December 30, 1976. Funding was provided by the National Science Foundation.

Scientific Personnel

James G. Quinn, Chief Scientist, GSO,URI
Mason Wilson, Co-Investigator, Mechanical Engineering, URI
Peter Cornillon, Co-Investigator, Ocean Engineering, URI
Malcolm Spaulding, Co-Investigator, Ocean Engineering, URI
Chris Brown, Co-Investigator, Chemistry, URI
Mark Ahmadjian, Research Assistant, Chemistry, URI
Pat Lynch, Research Assistant, Chemistry, URI
David Shonting, Co-Investigator, Naval Underwater Systems Center, Newport
Robert Morton, Co-Investigator, Naval Underwater Systems Center, Newport
Charles Finkelstein, Co-Investigator, Kline Associates, New Hampshire
Sheldon Pratt, Co-Investigator, GSO, URI
Dana Kester, Co-Investigator, GSO, URI
Doug Huizenga, Graduate Student, GSO, URI
Skip French, Graduate Student, GSO, URI
Eva Hoffman, Co-Investigator, GSO, URI
Joseph Kane, Technician, NMFS, Narragansett
William Hahn, Marine Technician, GSO, URI
Ted Benttinen, Marine Technician, GSO, URI

Objective

The objective was to investigate the effect of the *Argo Merchant* oil spill on Nantucket Shoals and surrounding waters.

Summary of Research Program

The following scientific programs were carried out during this cruise:

(1) Plankton and neuston samples were collected from surface waters using plankton and bongo nets. These samples will be analyzed for species abundance and diversity.

(2) Water samples were collected from depths of 1 meter, 6 meters, and the bottom, using 5-liter Niskin bottles. These samples will be analyzed for total hydrocarbons, oil droplet size distribution, total organic carbon, nutrients, temperature (°C), salinity (o/oo), pH, O_2, particulate trace metals, and total suspended material.

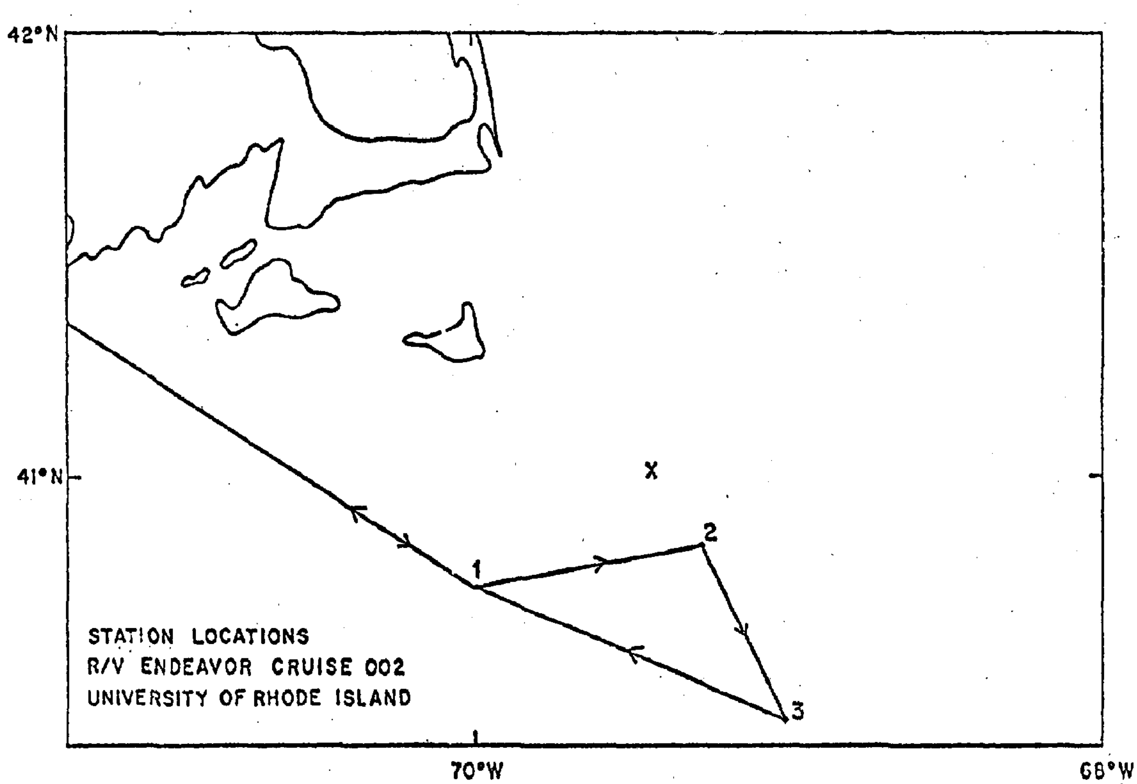
(3) Benthic samples were collected using a Smith-McIntyre grab sampler. These samples will be analyzed for species abundance and diversity and sedimentary hydrocarbons.

(4) Side scanning sonar measurements were taken as the ship approached station 1.

(5) One array of three current meters was released at the beginning of station 2.

The cruise tract followed is given in the accompanying figure. The locations of the stations occupied are tabulated along with information on the samples collected at these stations.

Total cruise occupied 49 hours, of which approximately 9 hours (18%) were devoted to station time. Total distance: ∿300 miles.



Endeavor Cruise EN-002 - sample locations and information

Station No.	Samples or operation	Date (Dec. '76)	Time	Loran-C
1	Side scan sonar in	29	0130	38035.9 49350.1
1	Plankton tow 1	"	0254	38033.8 49340.6
1	Plankton tow 2	"	0301	38035.1 49341.4
1	Side scan sonar out	"	0313	38039.9 49342.2
1	Sediment grab 1	"	0413	38032.2 49344.2
1	Sediment grab 2	"	0433	38032.2 49344.6
1	Sediment grab 3	"	0455	38033.1 49347.6
1	Hydrocast 1 (5-liter Niskins, 1 m, 6 m, bottom)	"	0455	38033.1 49347.6
1	Hydrocast 2 (5-liter Niskins, 1 m, 6 m, bottom)	"	0547	38031.4 49346.0
1	Neuston tow	"	0707	38031.2 49346.1
1	Bongo net tow	"	0750	38049.9 49363.9
2	Current meter array deployed	"	1420	37663.5 49219.2
2	Hydrocast (5-liter Niskins, 1 m, 6 m)	"	1514	37666.9 49218.8
2	Sediment grab 1	"	1600	37650.6 49213.2
2	Sediment grab 2	"	1610	37650.6 49213.2
2	Sediment grab 3	"	1620	37650.6 49213.2
2	Sediment grab 4	"	1630	37650.6 49213.2
2	Plankton tow	"	1650	37648.0 49211.6
2	Neuston tow	"	1700	37648.0 49211.6
2	Bongo net tow	"	1710	37648.0 49211.6
3	Surface water sample	"	2005	37416.8 49234.3

R/V *ENDEAVOR* CRUISE EN-003
JANUARY 26-29, 1977

Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

The R/V *Endeavor* departed Quonset, Rhode Island, at 1100, January 26, for Nantucket Shoals and surrounding waters, and returned to Quonset at 1600, January 29, 1977. Funding was provided by the National Oceanic and Atmospheric Administration (proposed), and by the Energy Research and Development Agency.

Scientific Personnel

Eva J. Hoffman, Chief Scientist, GSO, URI
Peter Cornillon, Co-Investigator, OE, URI
Dick Jadamec, Co-Investigator, Research Chemist, U.S. Coast Guard
Edward Myers, Co-Investigator, National Oceanic & Atmospheric Administration
Andrea Hurtt, Graduate Student, GSO, URI
Sheldon Pratt, Co-Investigator, GSO, URI
Jeff Hyland, Co-Investigator, GSO, URI
Charles Young, Technician, Mechanical Engineering, URI
Steven Buchanan, Marine Science Technician 2nd class, U.S. Coast Guard
F. Gene Franklin, Technician, Chemist, URI
Robert Bowen, Technician, Chemist, URI
Jim Hannon, Marine Technician, GSO, URI
Ted Benttinen, Marine Technician, GSO, URI
Natalie Houghton, Co-Investigator (Birds), Manoment Bird Observatory
Art Buddington, Marine Technician, GSO, URI

Main Objectives

A. To determine whether and where oil from the *Argo Merchant* has reached the bottom in the vicinity of the wreck and the resulting surface oil slick. This objective will be implemented by:

1. Collection of sediments, benthic organisms, and near-bottom waters from a variety of locations, at various depths, with various sediment types, and with varying times of surface oil contamination.

2. Sediment and near-bottom water samples to be screened for hydrocarbon content with shipboard instrumentation.

3. More extensive sampling of sediments, benthic organisms, and near-bottom waters in areas shown by rapid screening to be possibly contaminated with oil to determine the extent of such contamination.

4. Later detailed analysis of sediment samples to determine hydrocarbon levels in the sediment and to determine if high concentrations of hydrocarbons found by shipboard screening are specifically from the *Argo Merchant*.

B. To conduct a preliminary survey of the benthic community in the oil spill area. The data will be used in conjunction with possible long-term effect studies. This objective will be implemented by:

1. Collection and preservation of benthic organisms for use in later long-term studies; more extensive sampling in areas where the sediment has been shown by shipboard screening to contain significant concentrations of hydrocarbons.

2. Collection of benthic organisms for later hydrocarbon analyses.

3. Collection of benthic organisms for histopathologic study.

4. Collection of oil-contaminated sediments and clean sediments to be used in laboratory bioassay experiments, evaluating possible impact of oil on winter flounder hatchability and larval survival.

C. To determine to what extent oil has become entrained in the water column which may be moving with subsurface currents. This objective will be implemented by:

1. Collection of seawater samples at a variety of locations in the wreck vicinity at depths of 1 m, 6 m, and at the bottom to be analyzed at URI for hydrocarbon content.

2. Collection of seawater samples to determine the oil droplet size distribution.

D. To determine sea bird density and distribution in the oil spill area, with possible future application to long-term studies. This objective will be facilitated by:

1. Observations of sea bird density and distribution at each station during daylight hours.

2. Observation of numbers and species of oiled birds and any abnormal behavior patterns of these birds.

3. Collection of dead birds for later autopsy.

Ancillary Objectives

A. To determine how weathering changes the organic and inorganic chemistry of *Argo Merchant* oil.

B. To check and perhaps retrieve a current meter array at EN-002.

Sampling Station Selection Procedure

It is assumed that the following areas would be more likely to have significant quantities of *Argo Merchant* oil in the sediments than other locations (in approximate order of importance):

1. Areas whose sediments have been shown by chemical analysis to contain significant quantities of *Argo Merchant* oil.

2. Areas covered by the slick for the longest periods of time.

3. Shallower areas.

4. Areas covered by the slick when the sea state was high.

5. Any area covered by the slick at any time.

6. Any area possibly affected by subsurface currents, which could carry oil from slick areas to sediments a distance away from areas actually covered by the slick.

NOTE: Difference in sediment type was not considered because the area in question is quite uniform with regard to sediment type.

To date, none of the samples previously analyzed showed significant quantities of oil in the sediments. By examination of NOAA-USCG slick maps, two areas (referred to hereafter as Area A and Area B) were found to have been covered with heavy oil pancake concentrations or consolidated slicks bounded by 41°04'N and 40°54'N latitude and 69°35.2'W and 69°07'W longitude. Area B is an area where heavy concentrations of oil pancakes and slick stalled for 6 days before continuing to head east. Area B is bounded by 40°58'N and 40°33'N latitude and 68°53'W and 68°04'W longitude.

With plans to collect sediments and water samples at a maximum of 50 stations, 30 of these stations were randomly distributed within Areas A & B. Since Area A covers 210 square nautical miles and Area B covers 880 square nautical miles, Area A was assigned 6 stations and Area B 24 stations. From M. G. Natrella's Experimental Statistics Table of Random Numbers (NBS Handbook #91, U.S. Department of Commerce, 1963), a series of random numbers was selected. Within Area A each nautical square mile was numbered with square mile number 1 in the NW corner, number 10 in the SW corner, number 201 in the NE corner and number 210 in the SE corner. Within Area B, number 1 was in the NW corner, 24 in the SW corner, 865 in the NE corner, and 888 in the SE corner. The following square mile areas, arrayed as described above, were designated as sampling stations in Area A: 076, 184, 133, 169, 173, and 029 (alternates 190 and 004). In Area B, the sampling stations, the square mile numbers were: 732, 783, 571, 564, 405, 756, 544, 235, 409, 355, 820, 878, 876, 222, 346, 107, 583, 629, 444, 654, 236, 541, 692, and 089.

In addition to the 30 stations in areas A and B, another 3 stations were selected to examine sediments in shallower areas; 3 stations were selected in areas covered by heavy slick when the sea state was high; 2 stations were the the previous *Endeavor*-002 stations 1 and 2; and 2 stations were selected between Areas A and B.

Station number system. Stations chosen at random in Area A have the letter "A" as a prefix. Stations chosen at random in Area B have the letter "B" as a prefix. Stations chosen in shallower areas have the letter "C" as a prefix. Stations in areas covered by a heavy slick when the sea state was high have the letter "D" as a prefix. *Endeavor*-002 stations 1 and 2 have the letter "E" as a prefix. Stations between areas A and B have the letter "F" as a prefix. Additional stations chosen while at sea, based on the results of onboard screening results, will have a letter "G" as a prefix.

R/V *Endeavor* cruise EN-003 - station information

Station	Samples	Date	Local Time	Loran C	Latitude N Longitude W (deg/min)
E-1	Hydrocast (5-liter Niskins and 4-liter sterile bag samples at depths 1, 6 and 37 m)	1/26/77	2100	38029.1 70135.5	40 43.0 70 00.7
A-40	Hydrocast (5-liter Niskins and 4-liter sterile bag samples at depths 1, 6 and 47 m)	1/28/77	1407	37715.7 70114.0	40 56.3 69 30.7
A-40	Grab 1 (depth 42 m)	1/28/77	1418	37693.1 70107.6	40 58.1 69 29.7
A-40	Grab 2 (depth 34-42 m)	1/28/77	1429	37692.6 70107.0	40 58.3 69 29.5
A-40	Grab 3 (depth 42 m)	1/28/77	1446	37687.7 70105.1	40 58.8 69 29.2
C-37	Grab 1 (depth 30 m)	1/28/77	1507	37670.5 70112.6	40 57.9 69 26.3
C-37	Grab 2 (depth 36 m)	1/28/77	1517	37667.6 70111.8	40 58.2 69 26.0
C-37	Grab 3 (depth 36 m)	1/28/77	1524	37665.6 70111.1	40 58.4 69 25.9
C-37	Hydrocast (5-liter Niskins and 4-liter sterile bag samples at depths 1, 8 and 30 m)	1/28/77	1545	37665.55* 70114.20	40 57.8 69 25.4
A-38	Hydrocast (5-liter Niskins and 4-liter sterile bag samples at depths 1, 6 and 36 m)	1/28/77	1613	37643.35* 70108.55	40 59.5 69 24.4
A-38	Grab 1 (depth 41 m)	1/28/77	1642	37638.8 70106.8	40 59.7 69 24.2
A-38	Grab 2 (depth 44 m)	1/28/77	1653	37634.3 70105.9	41 00.2 69 23.6
A-38	Grab 3 (depth 44 m)	1/28/77	1703	37630.5 70104.7	41 00.5 69 23.5
C-39	Hydrocast (5-liter Niskins) and 4-liter sterile bag samples at depths 1, 6 and 44 m)	1/28/77	1738	37620.25* 70094.95	41 02.5 69 24.1

*Midpoint of hydrocast

R/V *Endeavor* CRUISE EN-004
FEBRUARY 8-12, 1977

Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

The R/V *Endeavor* is to depart Quonset, Rhode Island, at 1000, February 8, for Nantucket Shoals and surrounding waters, and return to Quonset at 1600, February 12, 1977. Funding to be provided by the National Oceanic and Atmospheric Administration (proposed) and by the Energy Research and Development Agency.

Scientific Personnel

Sheldon Pratt, Chief, GSO, URI
Robert Bowen, Technician, Chemistry, URI
M. M. Brady, Technician, Chemistry, URI
Steve Buchanan, Marine Science Technician 2nd Class, U.S. Coast Guard
Craig Schaarf, Bird Specialist, Manomet Bird Observatory
Dave Konigsbert, Student, Ocean Engineering, URI
William Hahn, Marine Technician, GSO, URI
Ted Benttinen, Marine Technician, GSO, URI
Barclay Collins, Graduate Student, GSO, URI
Doug Vaughn, Graduate Student, GSO, URI
Elwyn "Bud" Rolofson, NOAA-MESA, Boulder, Colorado

Main Objectives and Station Selection Procedure

The main objectives and station selection procedure were the same as for cruise EN-003. Station information is given in the table below.

R/V *Endeavor* cruise EN-004 - station information

Station No.	Random No.	Lat. N (deg/min)	Long. W. (deg/min)	Approx. depth (fathoms)	Miles from wreck	Miles to next station
E-1 (grabs only)	E	40 4.2	70 00.5	17-24	29	86
B-2	876	40 46 40 47	68 40.1 68 05.3	38	65	2
B-3	878	40 44 40 45	68 04.1 68 05.3	39	66	4
B-4	783	40 44 40 45	68 09.4 68 10.8	33-39	61	3
B-5 (optional)	756	40 46 40 47	68 10.8 68 11.8	30-35	60	1
B-6	732	40 46 40 47	68 11.8 68 13.0	30-33	59	9
B-7	820	40 54 40 55	68 07.0 68 08.2	29-31	61	8
B-8 (optional)	654	40 52 40 53	68 16.0 68 17.5	27	55	2
B-9	629	40 53 40 54	68 17.5 68 19.0	25	53	3
B-10	583	40 51 40 52	68 20.0 68 21.5	20-23	52	5
B-11	564	40 46 40 47	68 21.7 68 22.7	25-28	52	3
B-12	544	40 43 40 44	68 22.7 68 24.0	30	52	8
B-13	692	40 38 40 39	68 15.0 68 16.0	43	59	5
B-14 (optional)	571	40 39 40 40	68 21.5 68 22.7	37	54	0
B-15	571	40 39 40 40	68 21.5 68 22.7	37	54	7
B-16	405	40 37 40 38	68 30.1 68 31.6	36	49	3
B-17	355	40 39 40 40	68 33.0 68 34.2	30	46	5
B-18	236	40 38 40 39	68 39.7 68 41.0	32	42	1

R/V *Endeavor* cruise EN-004 - station information (continued)

Station No.	Random No.	Lat. N (deg/min)	Long. W. (deg/min)	Approx. depth (fathoms)	Miles from wreck	Miles to next station
B-19 (optional)	235	40 39 40 40	68 39.7 68 41.0	32	42	12
B-20	444	40 46 40 47	68 28.0 68 29.3	23	47	5
B-21	346	40 48 40 49	68 33.0 68 34.2	32	43	10
B-22	409	40 57 40 58	68 29.3 68 30.3	8-12	45	4
C-23	C	40 56.8	68 34.7	10	41	5
D-24	D	40 57.0	68 41.6	19	36	5
B-25	222	40.52 40 53	68 39.7 68 41.0	30	36	7
B-26	107	40 47 40 48	68 46.2 68 47.3	36	34	6
B-27	89	40 41 40 42	68 47.3 68 48.7	35	35	12
F-28	F	40 49.0	69 00	39	24	5
F-29	F	40 54.0	69 01.6	42	21	12
E-30	E	40 50.0	69 15.9	30	13	
A-31	169	41 41	69 11.5 69 10.3	33	12	7
A-32 (optional)	184	41 01 41.02	69 12.8 69 11.5	25	14	6
A-33	173	41 02 41 03	69 14.1 69 12.8	25	12	1
A-34	133	41 02 41 03	69 16.8 69 18.2	20-24	9	4
D-35	D	40 58	69 17.3	13	9	5
D-36	D	41 01	69 32	29	7	2
C-39 (grabs & water)	C	41 03	69 26.0	5-10	3	4
G-41		41 07	69 22			
G-42		40 54	69 36			

R/V *Endeavor* CRUISE EN-005 (PROSPECTUS)*
FEBRUARY 22-25, 1977

Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

The R/V *Endeavor* is to depart Quonset, Rhode Island, at 0830, February 22, for Nantucket, and return to Quonset at 1600, February 25, 1977. Funding is to be provided partly by the National Oceanic and Atmospheric Administration.

Scientific Personnel

Eva Hoffman, Chief Scientist, GSO, URI
Sheldon Pratt, Co-Investigator, GSO, URI
Robert S. Brown, Co-Investigator, Animal Pathology, URI
Patricia Boyd, Student, URI
Jack Greene, Plankton Physiologist, NMFS Narragansett R&D Center, Groton, Conn.
Scott Fortier, Staff Chemist, U.S. Coast Guard, R&D Center, Groton, Conn.
Bill Osberg, MST III, U.S. Coast Guard, R&D Center, Groton, Conn.
David Rudnick, Graduate Student, GSO, URI
Keith Cooper, Graduate Student
Vicki Murray, Research Assistant, Animal Pathology Department
Tatsusaburo Isaji, Student, Ocean Engineering, URI
Jim Hannon, Marine Technician, GSO, URI
Audrey Fillion, Graduate Student, McGill University
Renate Pollack, Graduate Student, McGill University

Main Objective

Determination of the areal extent of sediment contamination by *Argo Merchant* oil, the collection of benthic organisms, and deployment of bottom drifters.

Ancillary Objectives

1. Determination of depth of sediment contamination by *Argo Merchant* oil.

2. Determination of relationship between contamination of sediments and hydrocarbon content of benthic organisms in the area.

3. Determination of the density and relative abundance of benthic organisms retained by a 1-millimeter sieve.

*This cruise was conducted.

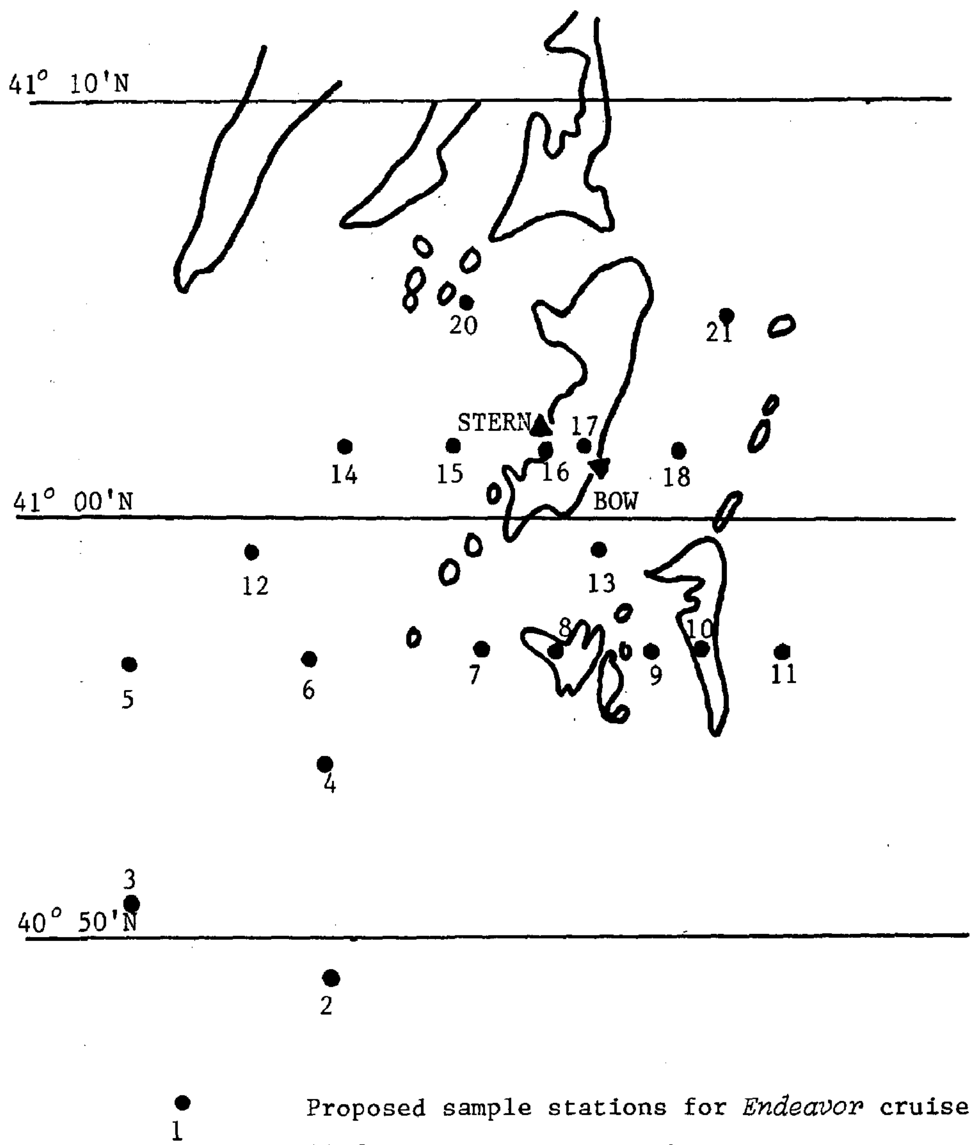
4. Archive and preserve sediment samples for future meiobenthic work.

5. Collection and description of phytoplankton in the area over contamination and uncontaminated sediments.

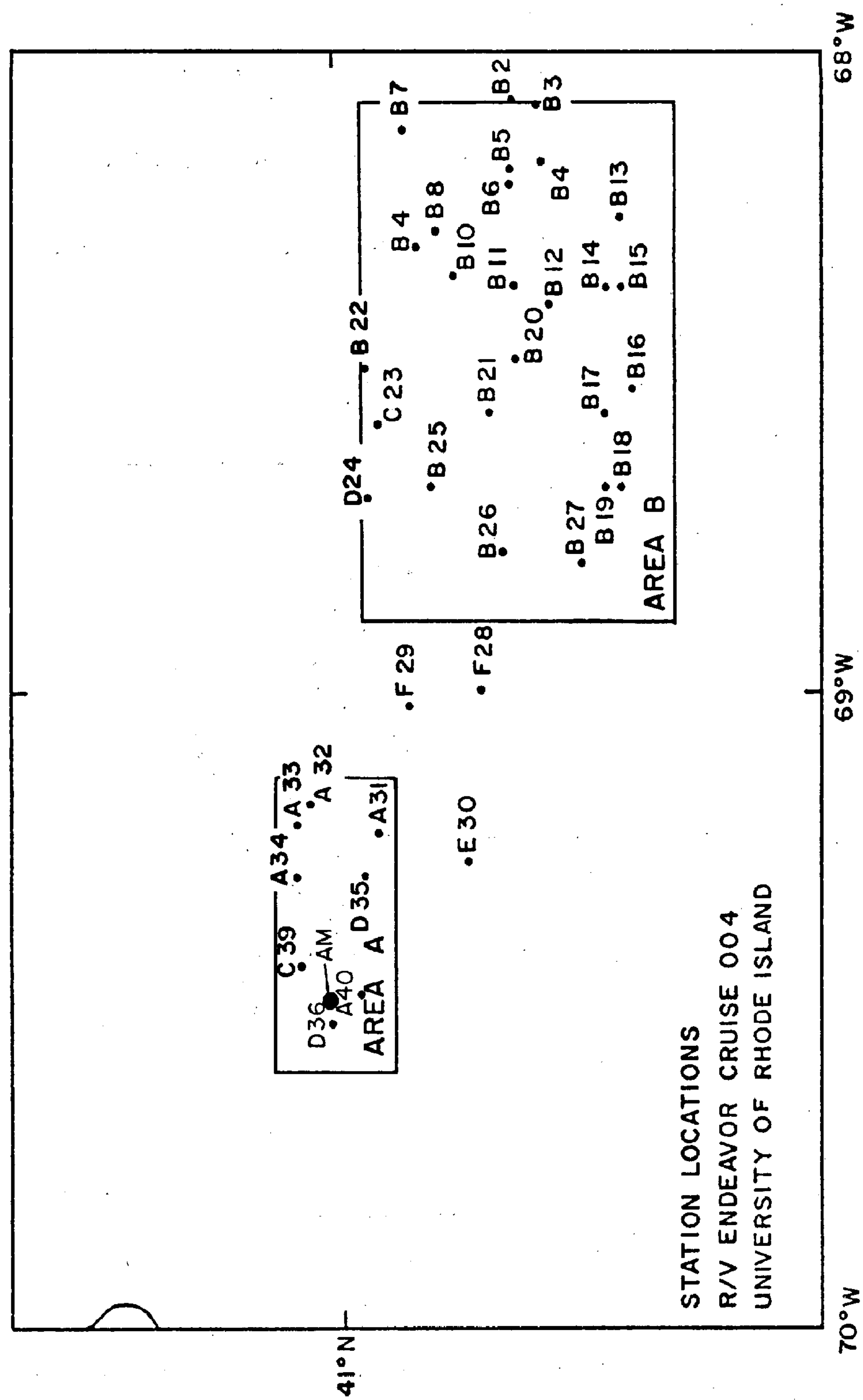
6. Collection of contaminated sediment and appropriate controls for laboratory studies (bioassays, benthic nutrient flux, O_2 uptake, etc).

7. Qualitative dredge samples for collection of epibenthos for histopathologic studies.

8. Collection of ichthyoplankton for oil effects research at NMFS.



Proposed sample stations for *Endeavor* cruise EN-005. 10-fathom contours are shown.


STATION LOCATIONS
R/V ENDEAVOR CRUISE 004
UNIVERSITY OF RHODE ISLAND
68°W
69°W
70°W
41°N
AREA A
AREA B
A31
A32
A33
A34
D35
D36
A40
AM
C39
E30
F28
F29
D24
C23
B22
B25
B26
B27
B21
B20
B19
B18
B17
B16
B15
B14
B13
B12
B11
B10
B8
B7
B6
B5
B4
B3
B2

REPORT OF A SURVEY OF THE INTERTIDAL ZONE NANTUCKET ISLAND, DECEMBER 27-29, 1976

The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts 02543

Abstract. On December 27 and 28, 1976, a field party surveyed the beaches, harbors, and marshes of Nantucket with the objective of providing crude baseline data for appraisal of the effects of any oil that might wash ashore from the *Argo Merchant* spill. The study relied on three transects for samples, one on the eastern end of South Beach in an area of rapid mineral and organic deposition, one on the north shore beach, and one on Eel Point across a marsh. A fourth set of samples was taken from the harbor bottom near the University of Massachusetts Field Station. The sampling is being used both as background information and, for this spill, to provide evidence as to how to design such a sampling program in the future, as well as to provide a guide for long-term studies designed for better resolution of the effects of toxins on the coastal zone.

Introduction

At the request of H. Curl of NOAA, Boulder, Colorado, a group of scientists met at 0900, Sunday, December 26, in Hyannis, Massachusetts, to design a sampling scheme capable of describing the biota of the intertidal zone of Nantucket Island prior to the arrival of oil from the *Argo Merchant* spill on Nantucket Shoals, about 27 miles southeast of Nantucket.

The challenge was twofold: first, to obtain data from Nantucket immediately, because there was a real possibility that the oil would wash ashore within hours; second, to design a scheme for the longer-term appraisal of the potential biotic effects of oil or other toxins on the intertidal zone. The immediate challenge of Nantucket dominated this meeting, and this report is limited to the activities in response to the emergency. No data are ready at this time.

All recognized that no thoroughly adequate or satisfacoory sampling would be possible. Such a study would require repetitive samplings over years to describe seasonal changes as well as the normal variability of the local plant and animal populations. Nonetheless, a brief survey seemed appropriate, both to provide information immediately on Nantucket and to provide background as to what was necessary in making such an appraisal.

The following scientists participated in the survey:

G. M. Woodwell, Marine Biological Laboratory, Woods Hole.
J. E. Hobbie, Marine Biological Laboratory, Woods Hole.
B. J. Peterson, Marine Biological Laboratory, Woods Hole.
M. J. Jordan, Marine Biological Laboratory, Woods Hole.

H. L. Sanders, Woods Hole Oceanographic Institution, Woods Hole.
G. R. Hampson, Woods Hole Oceanographic Institution, Woods Hole.
M. P. Morse, Northeastern University, Marine Science Institute, Nahant.
T. Novitsky, Energy Resources Company, Cambridge, Mass.
W. Tiffney, University of Massachusetts Field Station, Nahant.
Students (2) and assistants (3).

Sampling Design

The design that emerged from these and other discussions during the ensuing 24 hours, modified slightly by practical experience on Nantucket in a storm in December, was as follows:

Sampling was restricted to 4 transects, three that had a high probability of being oiled in the immediate future and a fourth that was representative of the biotically rich embayments of the area. The sites were:

(1) The ocean beach adjacent to the LORAN Station. This is a place of sand deposition, where floating organic matter normally accumulates both in the surf and on the beach. If oil were present nearby, it would probably accumulate here.

(2) The north shore beach near Capaum Pond, a place chosen because it is representative of the northern shore and is easily accessible.

(3) The Eel Point Marsh on the western tip of the island. If oil were to reach the southern shore of Nantucket, it would almost certainly be carried into Maddaket Bay and ultimately reach this southward-facing marsh and the bay adjacent to it.

(4) Nantucket Harbor adjacent to the University of Massachusetts Field Station. The harbor supports an extremely rich shellfish harvest, especially scallops. The benthic sediments were sampled to provide baseline data in the event of oiling. Due to poor weather only two sets of samples were obtained from this site.

At the beach and marsh sites the sampling was by transects with stations selected to include major life zones, especially the high-strand line, the midbeach zone, and the low-tide zone.

The need for extending the sampling below the low-tide zone was recognized, but no sampling could be done at that time except in the bay.

Samples were taken as follows, and in quintuplicate insofar as possible:

Oil. (a) On the beach sites, five 1-dm^2 plots 5 centimeters deep were collected into separate bottles from each of three sites along the transect (T. Novitsky, ERCO); (b) specially prepared 20-liter carboys were filled with water from the harbor and beach (T. Novitsky, ERCO); and (c) a visual survey for oil, tar balls, traces of asphalt or other evidence of petroleum contamination was carried out along at least a mile of beach at each site sampled.

No trace of oil was found in any part of this survey by any of the three people who participated in various phases of it (M. Jordan, G. Woodwell, J. Hobbie, MBL).

Bacteria. Sediment and water samples for bacteria were taken at each sampling site. Samples are being counted by a direct count method using acridine-orange stain and epifluorescent illumination. In addition, selected samples from each transect were assayed for bacterial metabolism using labeled amino acids (J. Hobbie, B. Peterson).

Benthic microalgae. At each site, samples of surface sediments were taken for determination of chlorophyll content as a measure of microalgae (primarily diatom) biomass. These analyses are being done now. Samples were preserved with formaldehyde for taxonomic enumeration of diatons (J. Hobbie, B. Peterson).

Benthic macrofauna. Samples were collected along transects at each site. The sampling quadrants were measured to correspond in size and depth to samples taken with the Van Veen grab in the subtidal. Samples preserved with formalde hyde. These samples were taken by Howard Sanders and his colleagues and will be sorted in a preliminary analysis to appraise the sampling technique. If oil comes ashore, these samples will be available for background data (H. Sanders).

Benthic meiofauna (small invertebrates of interstitial waters in coarse sands). Samples were taken at several levels at the two beach sites and at several additional sites by W. Patricia Morse and her students. These samples are being analyzed (P. Morse).

The strand line. Organic debris on the strand line was collected randomly and preserved. A more extensive collection of the full range of macroalgae that could be found along a mile of beach was also made Samples were preserved for later analysis (M. Jordan).

Photographers. The sampling program was documented estensively by two photographers. A set of "standard" photographs was taken at each transect and at each station looking in the cardinal directions.

Description of Transects

South Shore - Southwest of the town of Siasconset and immediately east of the USCG Loran Station. The base point of the transect is at the edge of the permanent dune, approximately 2 meters higher than the high tide. The transect runs due south* from this base point. The base point is about 20 meters west of a small sand road that runs perpendicular to the beach. A small antenna 73.8 meters north forms a range with the chimney of a house on

*All directions of the compass given in this report are magnetic and have not been corrected to true north.

the main road to form sightline A. From a transit set at the base points, the angles of the various sights and sightlines were as follows (all referenced to magnetic north as 0°, east as 90°, etc.):

Sight A. 341° to the nearby antenna (73.8 meters to its concrete base). This antenna is in line with the chimney of a a house on main road.

Sight B. 23.8° to telephone pole in front of water tower of town on Siasconset.

Sight C. 180° to transect line.

Sight D. 270.2° to the westernmost antenna of the pair (largest) on either side of government building.

Sight E. 274.8° to easternmost antenna close to Sight D.

Sight F. 317.8° to high antenna near main road.

Station 1. 45.55 meters south of base point. This is at the high or storm strandline.

Station 2. 55.0 meters south of base point.

Station 3. 67.28 meters south of base point. This is at the highest point the waves reach at low tide.

North Shore - North of the parking lot of the beach access road that passes to the east of Capaum Pond. It is directly west of the town of Nantuc ket. The base point is on the permanent dune, which is about 5 meters high. The transect runs due north from this point.

From a transit set at the base point, the angles of the various sights were as follows (all referenced to magnetic north as 0°, east as 90°, etc.):

Sight A. 64.3° to middle of peak of Hyde House.

Sight B. 159.0° to righthand side of large water tower.

Sight C. 174.6° to midpoint of chimney of house.

Station 1. 14.4 meters north of base point. This is at the high or storm strandline.

Station 2. 18.9 meters north of base point.

Station 3. 25.3 meters north of base point. This is at the edge of the waves at slack tide.

Eel Pond Marsh - The base point is at the northeast edge of Maddaket Harbor at the west end of the island at the edge of a low salt marsh next to a metal stake, 140.8 meters from the edge of the water along Sightline A. From a transit set at the base point, the angles of the various sights were as follows (all referenced to magnetic north as 0°, east as 90°, etc.):

Sight A. 212.0° to transect line.

Sight B. 165.2° to west chimney of houses.

Sight C. 124.4° to line of telephone poles.

Sight D. 224.8° to westernmost telphone pole on Smith Point.

Station 1. 17.0 meters from base point.

Station 2. 47.5 meters from base point.

Station 3. 71.5 meters from base point.

Station 4. 98.8 meters from base point.

Station 5. 130.8 meters from base point.

Station 6. 135.8 meters from base point.

Station 7. 140.8 meters from base point.

Nantucket Harbor - Northwest from the University of Massachusetts Field Station on the Polpis Road. The first station was in the middle of the har bor and the second station was one-fifth of the way back (five stations were planned but dangerous weather allowed only two to be sampled). Small buoys were left for a short-term reference point (H. Sanders, WHOI).

Results

Only those samples that cannot be stored are being analyzed immediately in detail. These are the microbial samples, samples for chlorophyll, and preliminary identification of living meiofauna and macrofauna. No other samples will be analyzed for the moment. These analyses will provide a basis for appraising the effectiveness of the sampling.

Follow-up Studies

(1) The probability seems high that oil from this spill will come ashore at one time or another on Nantucket and other areas along the eastern seaboard, including eastern Cape Cod, Martha's Vineyard, and elsewhere. A systematic sampling of these areas in advance of the oil is clearly desirable. The question is how intensive this survey should be. The answer will depend in part on the results of the study of Nantucket.

(2) The transects should be continued into the coastal waters to a depth of 30 to 50 feet, where the data from oceanographic vessels is assumed to apply. The sampling must, of course, be from a boat and should be stratified to include representative bottom types. Proper collections of epiphytes and the fauna and flora of hard bottoms is possible only by divers who cannot work safely in waters around Nantucket in winter. A cruise of the R.V. *Verrill*, or an equivalent vessel (from MBL), to Nantucket is planned for the week of January 10 to complete this sampling. The total sampling with modifications indicated by this experience should be repeated at least quarterly to account for seasonal variations.

(3) More measurements of "heterotrophic potential" are required. We were able to do only 5 measurements (out of 12 possible) because of lack of time and manpower. The "heterotrophic potential" measurement has two parts: (a) measurement of the rate of incorporation of the organic substrate (e.g., glutamic acid - ^{14}C) into particulate matter; and (b) rate of release of $^{14}CO_2$ from the organic matter (mineralization). We were able to do only part (a) and only on a limited number of samples. Part (b) should be run as well.

(4) If the oil comes ashore we will have the following control data: (a) preoiling survey data from these studies; (b) unoiled sites nearby; and (c) a comprehensive survey of earlier studies in the area. A sampling plan is being designed to appraise the effects, both shore and long-term.

APPENDIX VI

Overflight Descriptions

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/16/76	SOR Cessna 182	0930	1200	Chan Hufford				x			Vertical Oblique	Current probes Flew extent of slick
12/16/76	SOR Cessna 182	1430	1630	Hooper Mattson								Did not reach scene
12/17/76	USCG HU-16E	1145	1558	Grose Hufford Deaver	x	x		x			Slides Video tape by USCG	Terminated due to weather after two legs south of spill area
12/18/76	USCG HU-16E	0837	1421	Hooper Deaver Hufford	x	x		x		x	Slides	
12/18/76	NAA/EPA TU 206										Vertical 9 x 9 color	Only one usable because of weather
12/19/76	SOR Cessna 182	0930	1335	Grose Chan Frye				x	x		Slides	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/19/76	USCG H03 (Helo)	0948	1337	Deaver Mattson Galt	x		x	x	x	Slides	Dye work at tip of slick. ART broke
12/19/76	NASA C-54	1012	1104	Navarro Lineberger	x					Vertical high-altitude 9 x 9 false color IR	202 frames
12/19/76	NAA/EPA TU 206	0800	1100							Vertical high-altitude 9 x 9 color	26 frames
12/20/76	USCG	0915	1253	Mattson Kennedy Deaver	x		x				Dye work at tip of slick. ART broke
12/20/76	SOR Cessna 182	1430	1500	Chan Kolpack							Terminated due to weather
12/20/76	URI	1320	1555	Winn Scott		One seal				Slides	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/21/76	USCG H-3 (Helo)	1245	1423								Slides	
12/21/76	USCG HU-16E			Deaver Kennedy	x	x	One whale				Slides	
12/21/76	USCG H-3 (Helo)	1515	1718	Galt Lease Fortier				x		x	Slides	
12/22/76	NASA Landsat II										Imagery	90% obscured by clouds
12/22/76	USCG HU-16E	1005	1618	Deaver Kennedy		x	One whale				Slides	ART broke
12/22/76	USCG H-3 (Helo)	1044	1237									

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/22/76	USCG H-3 (Helo)	1400	1700	Chan Fortier						x	Slides	Sample with R&D sampler
12/22/76	AMSI PA-23	1505	1640	Frye Flynn Lukens	x						Vertical Oblique	
12/22/76	NASA C-54										Vertical 9 x 9 false color IR	
12/22/76	NAA/EPA TU 206										Vertical 9 x 9 color	199 frames
12/22/76	URI	1250	1520	Winn Scott							Slides	Mammal survey
12/23/76	USCG H-3 (Helo)	0855	1156	Kennedy							Slides	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/23/76	USCG HU-16E	1035	1608	Deaver	x	x	One whale	x				
12/23/76	AMSI PA-23	1140	1607	Frye Flynn Kielhorne		x	Two whales	x			Vertical Oblique	Radiometer out of commission
12/23/76	USCG H-3 (Helo)	1257	1325	Kennedy							Slides	
12/23/76	NASA Landsat II										Imagery	70-80% cloud cover. No oil identified
12/24/76	USCG HU-16E	0945	1534	Kegler Deaver	x	x					Slides	
12/24/76	AMSI PA-23	0948	1352	Flynn Cook Kielhorne	x	x		x	x	x	Oblique Vertical	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
12/24/76	USCG H-3 (Helo)	1014	1247	Butler Chan* Burger							Slides	*Took Niskin sterile bag samplers to the *Vigilant*. Briefed MSO on use of samplers.
12/25/76	USCG HU-16E	1018	1705	Kegler Deaver		x					Slides	Located "pancake 1." *Vigilant* took samples on "pancake 1." ART broke
12/26/76	USCG HU-16E	0916	1316	Deaver Kegler Myers		x				x	Slides	Relocated "pancake 1." Dropped drift cards on "pancake 1."
12/27/76	USCG H-3 (Helo)	0902	1113	Mattson Feely Hooper							Slides	
12/27/76	USCG HU-16E	0912	1443	Kegler Deaver		x					Slides	Relocated "pancake 1." Dropped data marker buoy "DMB." ART broke

Overflight descriptions: ART = airborne radiometric temperatures; W = current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep.	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	O	Δ	Photos	Remarks
12/27/76	AMSI PA-23	1324	1630	Flynn Kielhorne Scarlet	x	x			x		Vertical Oblique	Deployed drift cards
12/30/76	AMSI PA-23	1002	1340	Frye Flynn Kielhorne	x	x		x			Vertical Oblique	Dropped drift cards. No oil located. Worked W of *Argo Merchant*
12/30/76	USCG H-3 (Helo)			Baxter							Slides	Dropped drift cards
12/31/76	AMSI PA-23	1254	1534	Frye Flynn Kielhorne	x	x		x	x	x	Vertical	
12/31/76	USCG HU-16E			Deaver Baxter Anthony	x	x					Slides	
12/31/76	USCG H-3	1452	1930	Grose Pizzelo								Deployed buoy on "pancake 1" at 1500

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. (GMT)	Arr. (GMT)	Participants	ART	Map	Mammal	Currents W	Currents O	Currents Δ	Photos	Remarks
1/1/77	USCG HU-16E			Deaver Baxter								Flight aborted because of weather
1/1/77	AMSI PA-23			Flynn				x			Vertical	Rough seas. Spotted some dye markers
1/2/77	USCG HU-16E			Deaver Baxter Anthony	x	x					Slides	
1/3/77	USCG HU-16E			Deaver Baxter Anthony	x	x					Slides	Slick observed both morning and evening
1/3/77	USCG H-3 (Helo)	0845	1030	Kegler Kennedy Swope					x	x	Slides	No leaking or slick observed
1/3/77	NASA C-130										Vertical 9 x 9 color and false color IR	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurement; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. Arr. (GMT)	Participants	ART Map	Mammal	Currents W	O	Δ	Photos	Remarks
1/4/77	USCG H-3 (Helo)		Anthony Kennedy Galt	x		x	x	x	Photos	Dropped two current probes. Leaking and slick observed
1/5/77	USCG H-3 (Helo)			x						
1/5/77	USCG HU-16E		Anthony	x						
1/5/77	SOR Cessna 182		Baxter Morson	x						
1/5/77	NASA C-130								Natural color and color IR	
1/6/77	NASA C-54								Natural color and color IR	

Overflight descriptions: ART = airborne radiometric temperatures; W = water current measurements; O = oil velocity measurement; Δ = differential velocity measurement (continued)

Date	Agency Aircraft	Dep. Arr. (GMT)	Participants	ART	Map	Mammal	Currents			Photos	Remarks
							W	O	Δ		
1/9/77	NASA Landsat II									Multispectral imagery	20% cloud cover over area. No oil identified on surface
1/12/77	NOAA C-130		Baxter		x						Saw drift cards in oiled area
1/13/77	NOAA C-130		Baxter		x						

APPENDIX VII

Miscellaneous Tables and Figures

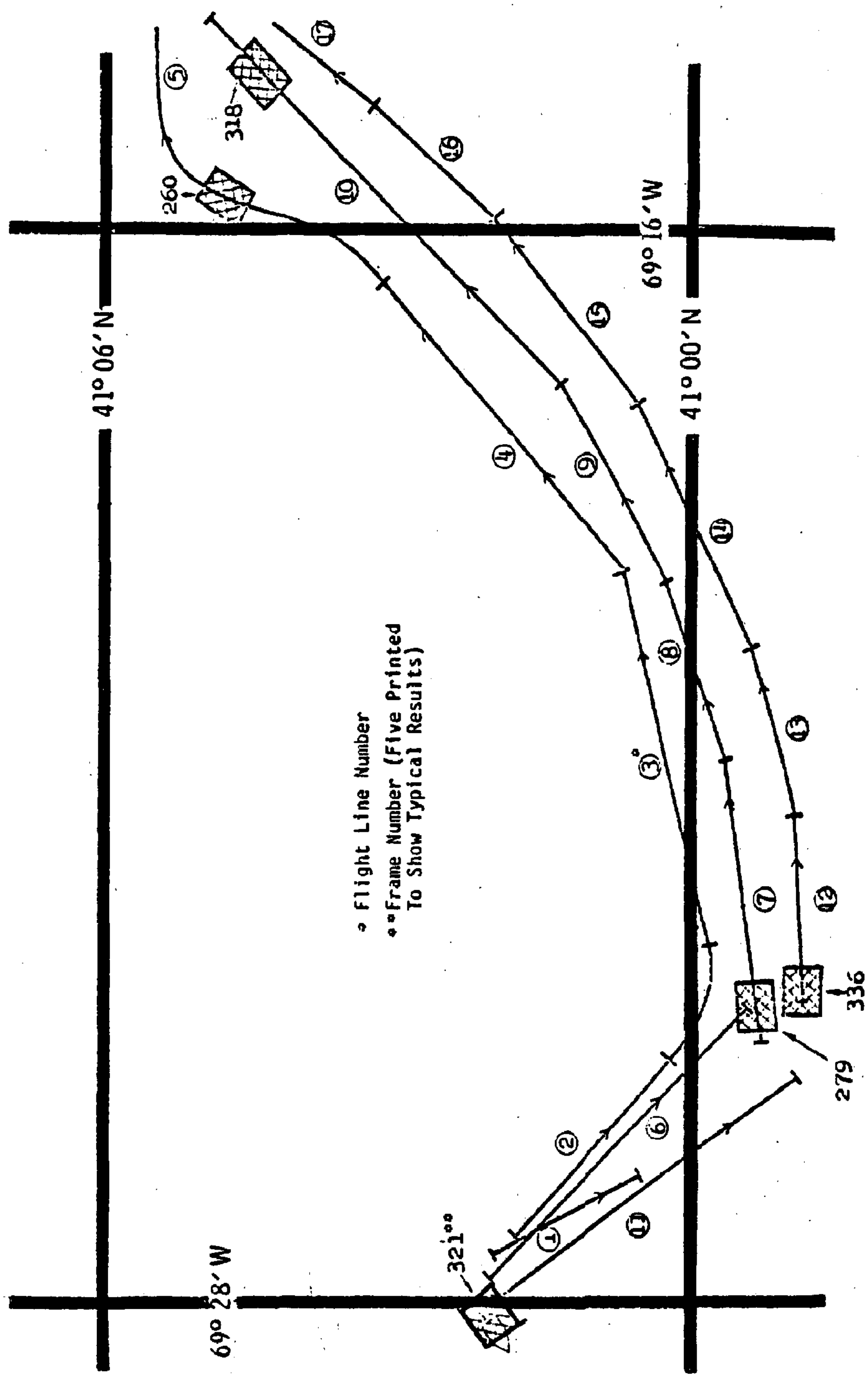


Figure VII-1. Flight lines for NASA flight on December 22, 1976.

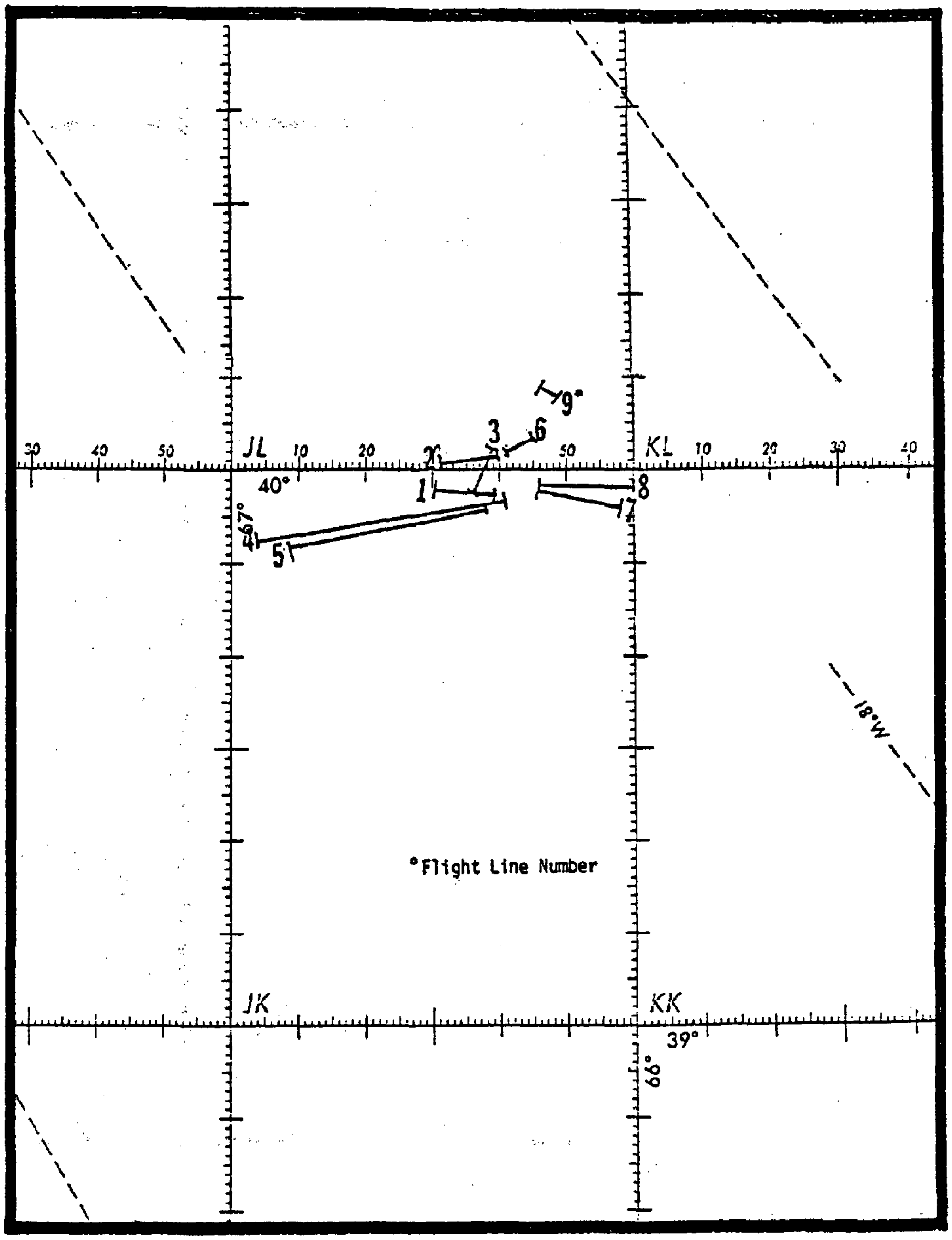


Figure VII-2. Flight lines for NASA flight on January 3, 1977.

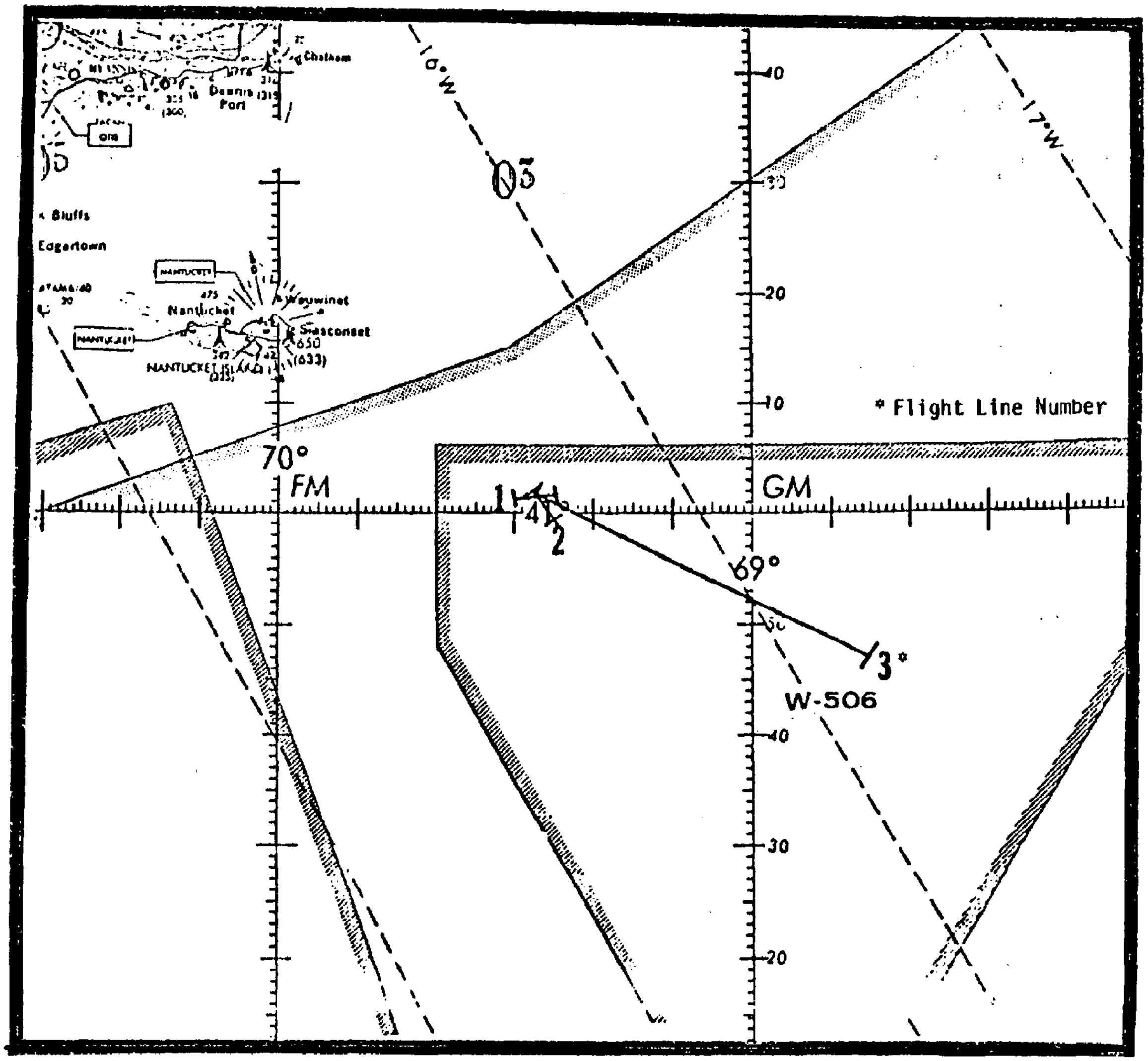


Figure VII-3. Flight lines for NASA flight on January 5, 1977.

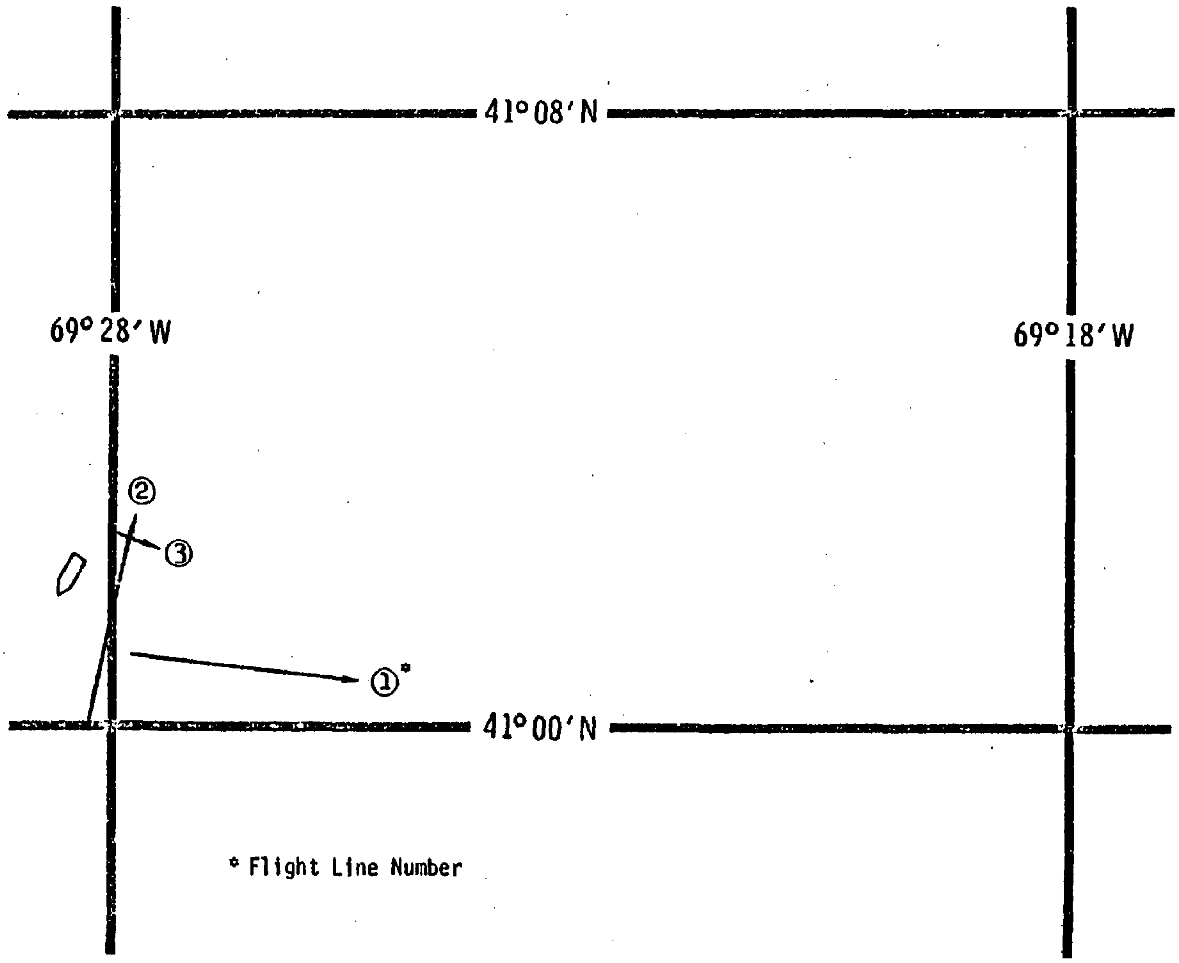


Figure VII-4. Flight lines for NASA flight on January 6, 1977.

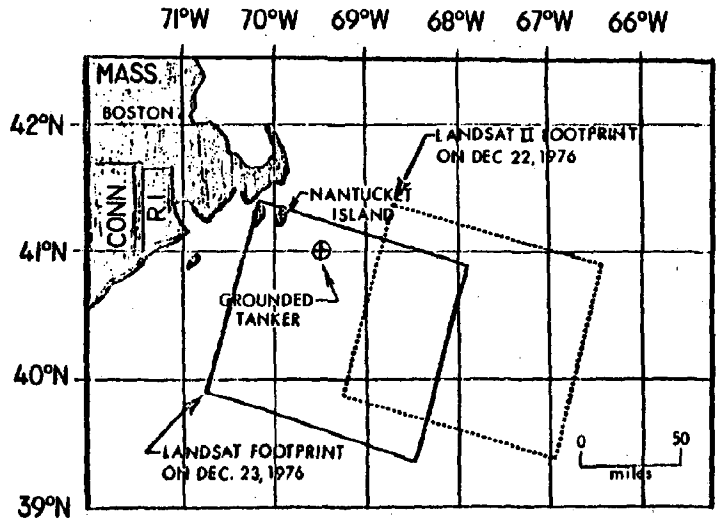


Figure VII-5. Locations of Landsat II images for December 22 and 23, 1976.

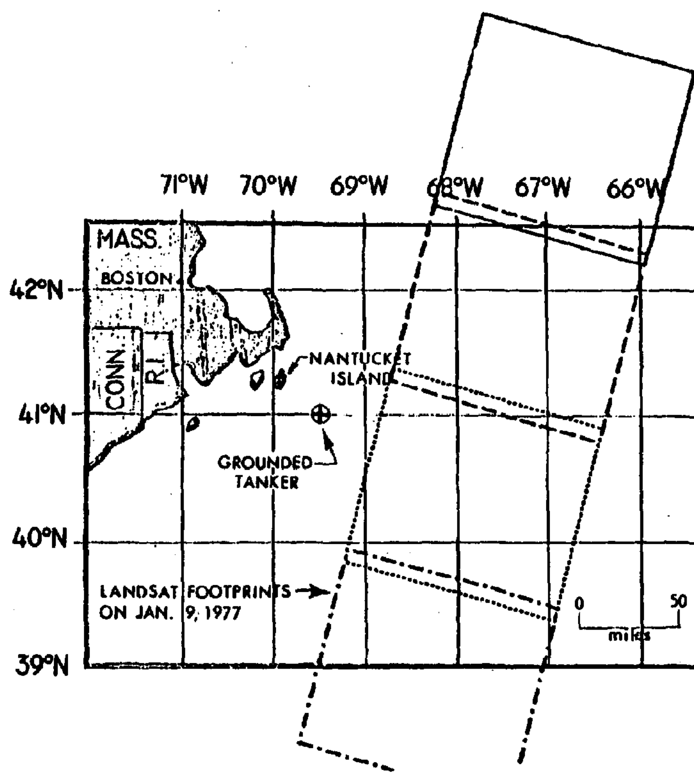


Figure VII-6. Locations of Landsat II images for January 9, 1977.

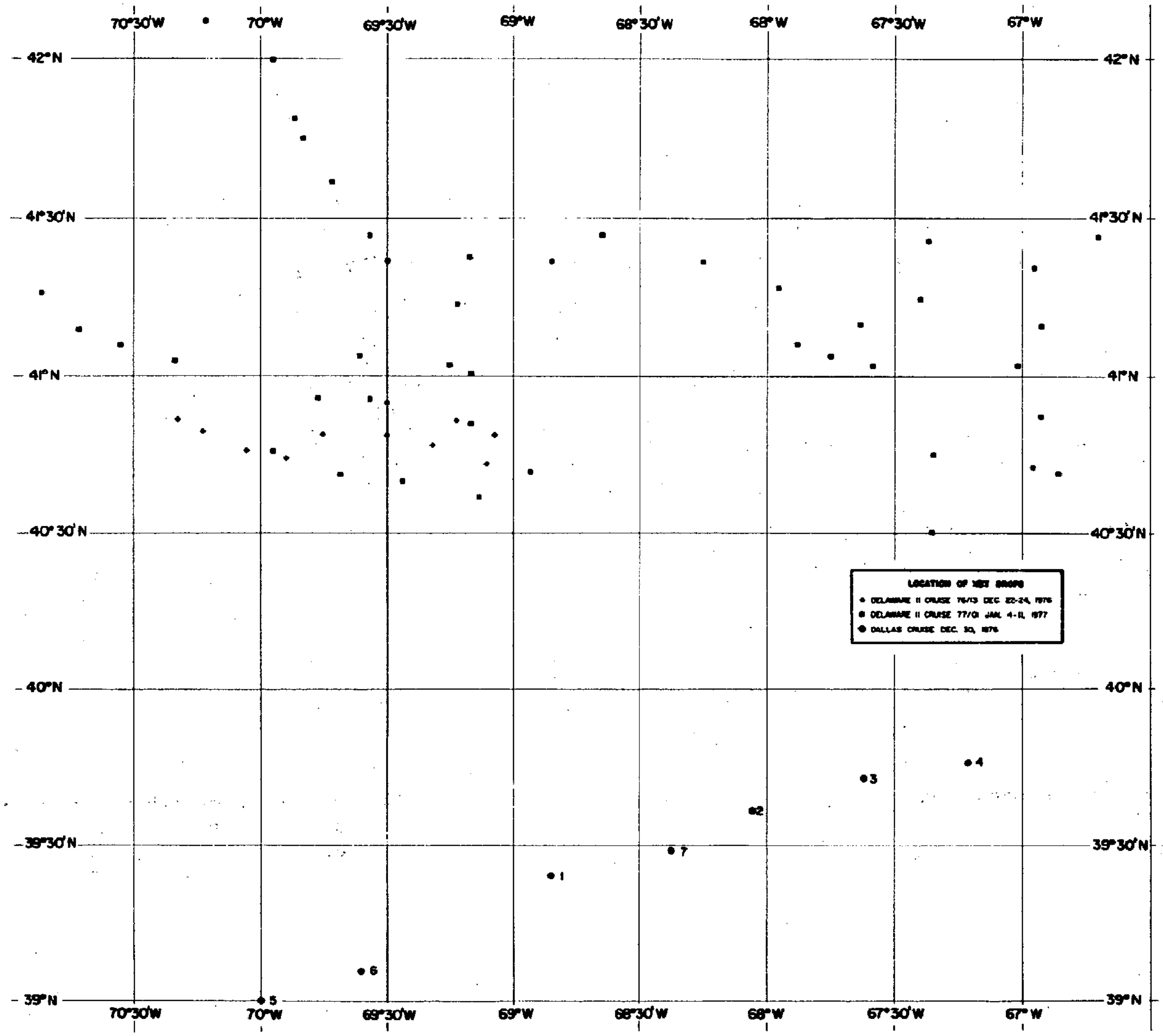


Figure VII-7. Locations of XBT casts.

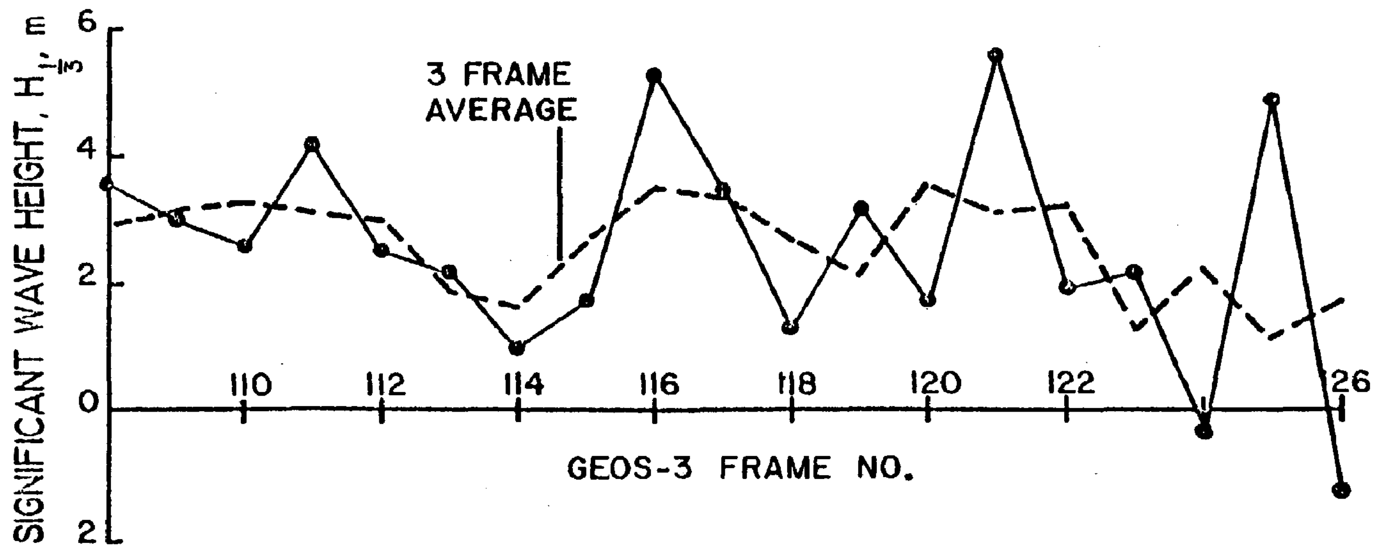


Figure VII-8. Significant wave height in the vicinity of the *Argo Merchant*, December 24, 1976.

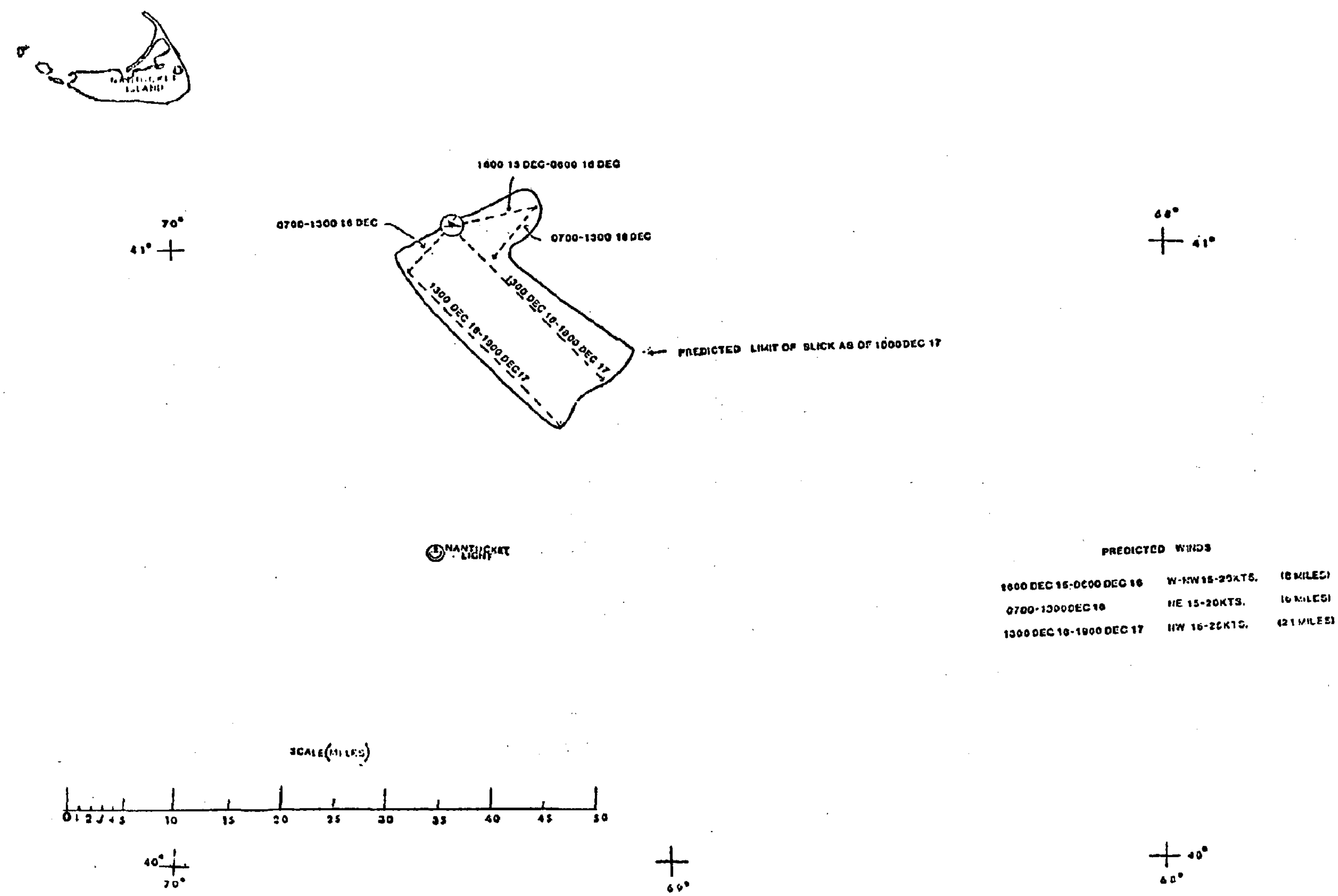


Figure VII-9. Predicted limit of slick as of 1900, December 17.

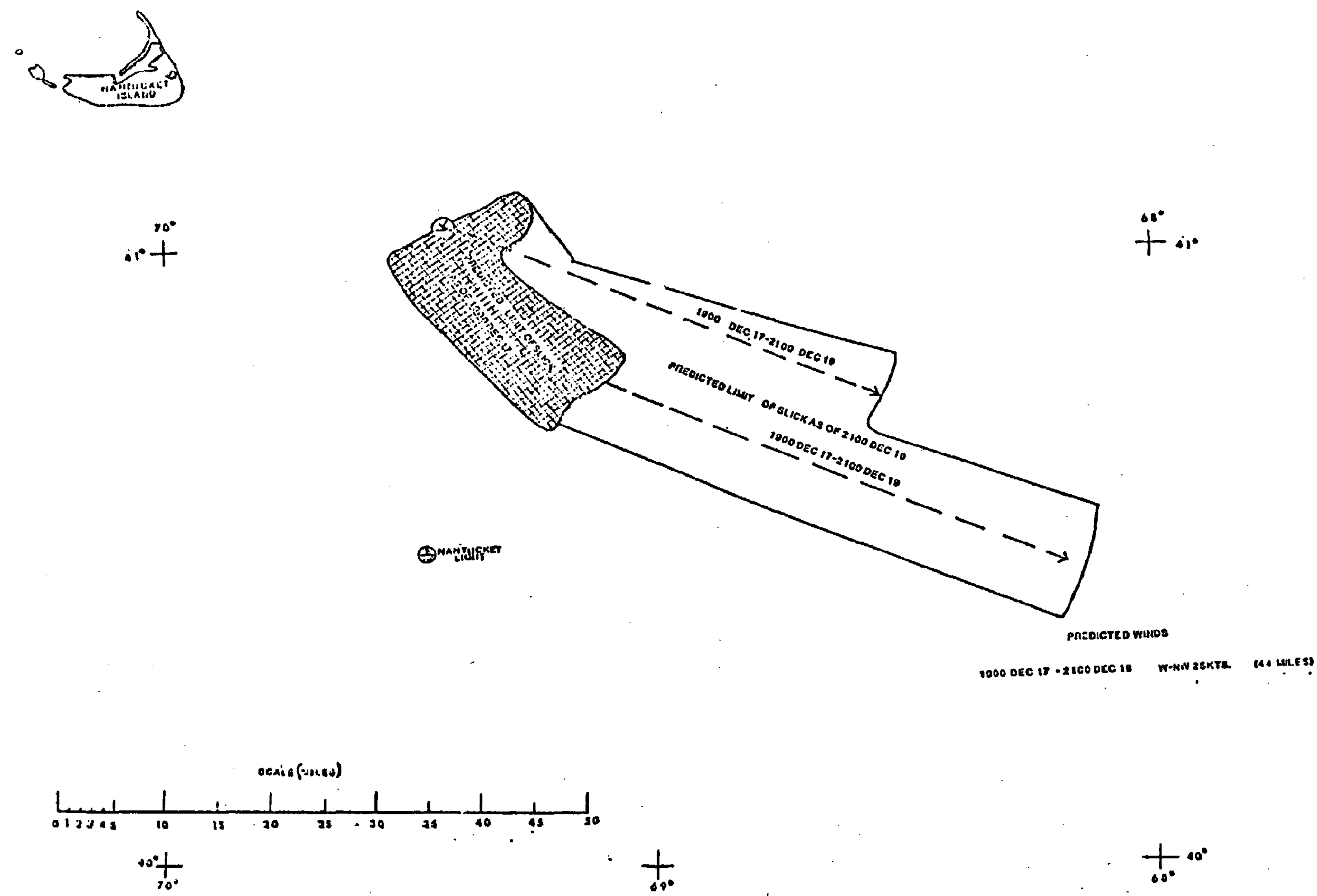


Figure VII-10. Predicted limit of slick as of 2100, December 19.

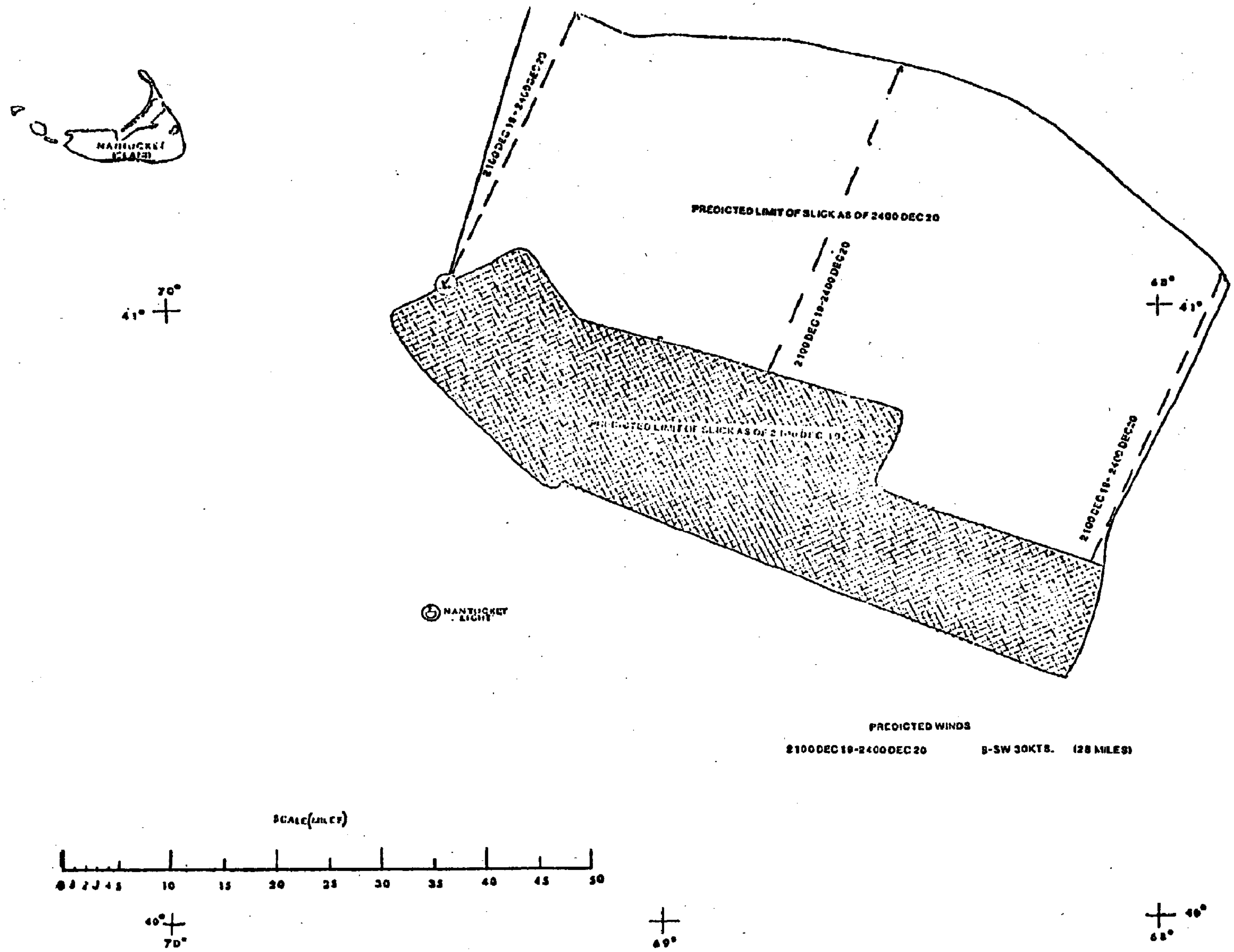


Figure VII-11. Predicted limit of slick as of 2400, December 20.

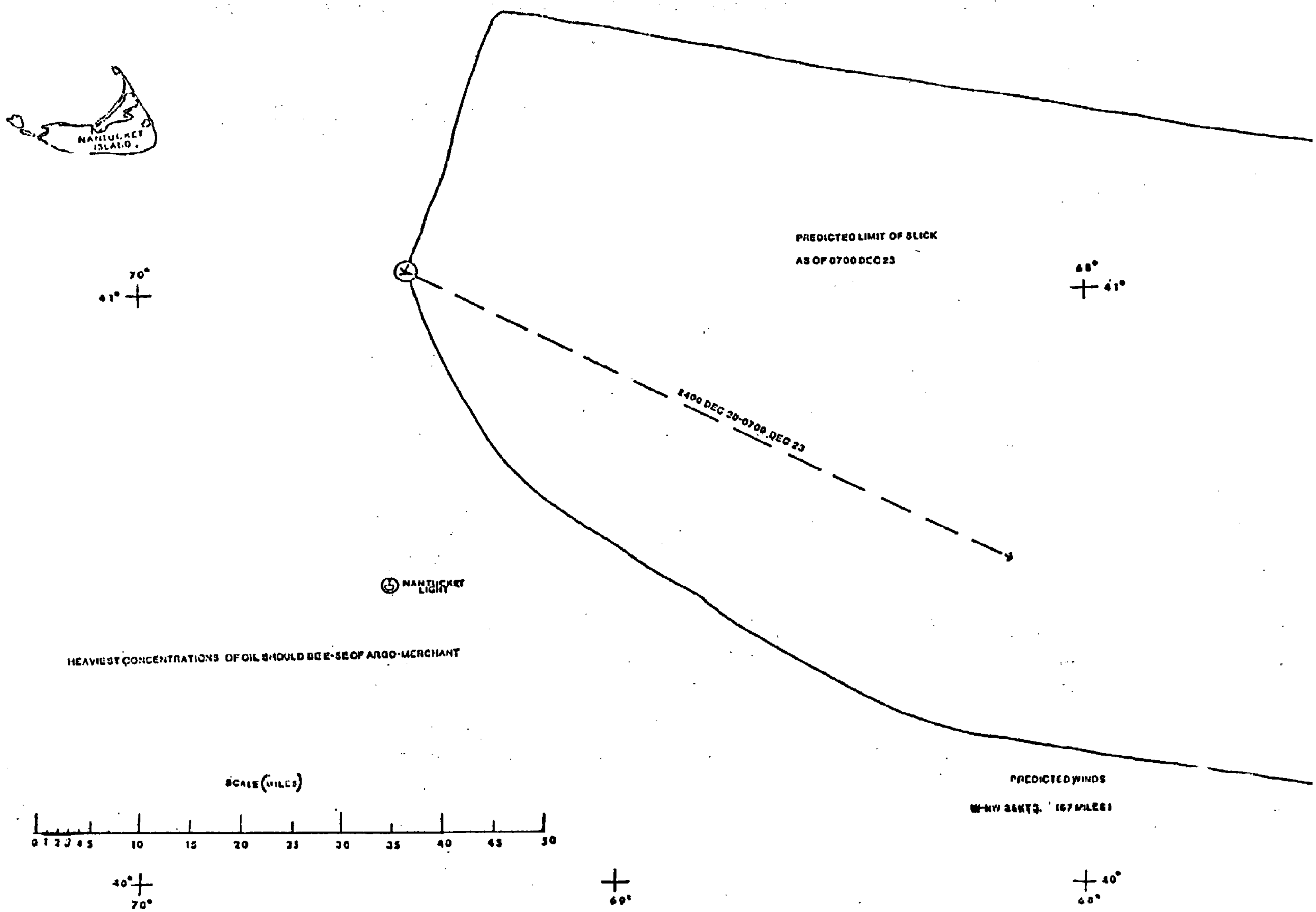


Figure VII-12. Predicted limit of slick as of 2400, December 23.

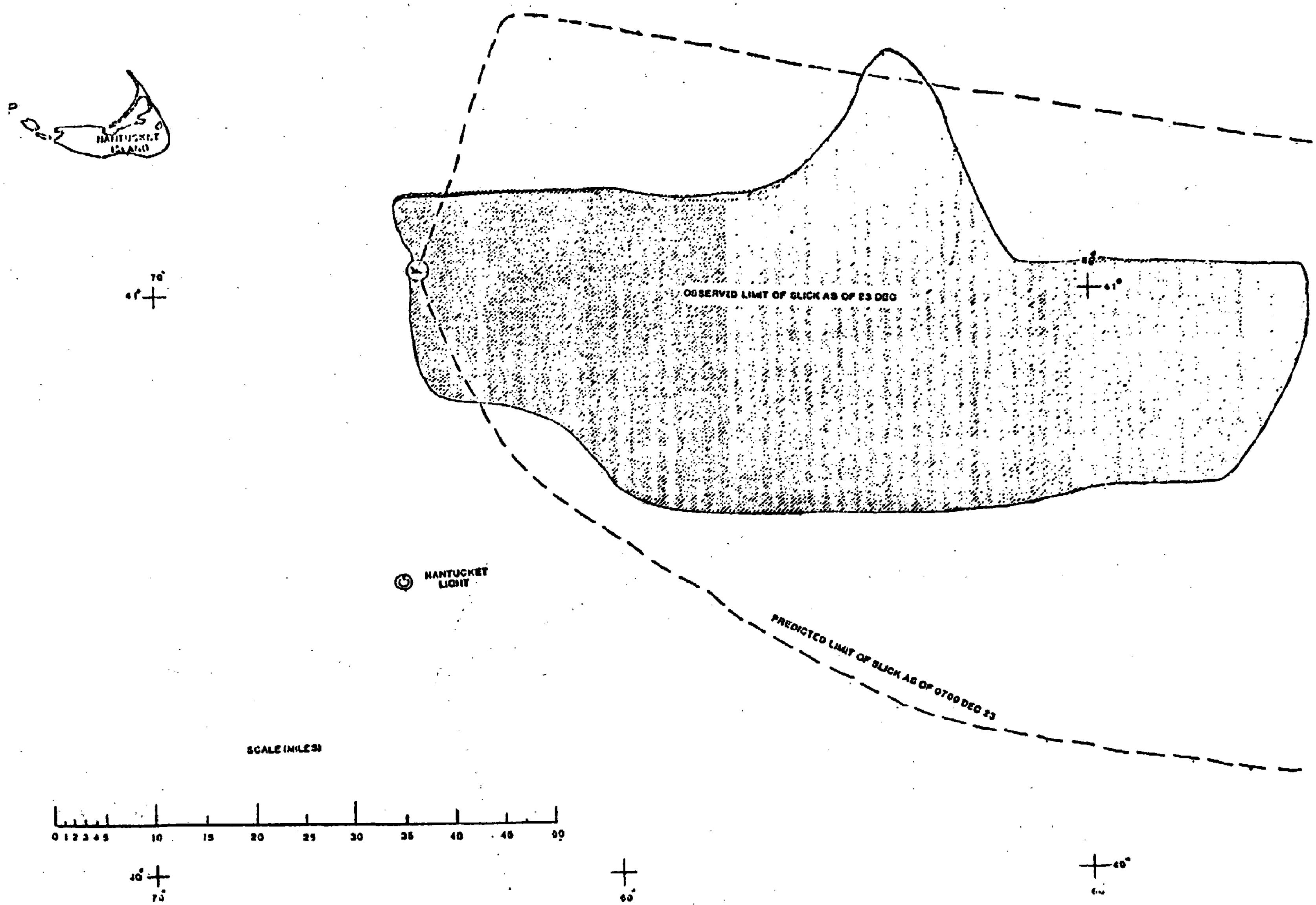


Figure VII-13. Comparison of observed and predicted circuit of slick, December 23.

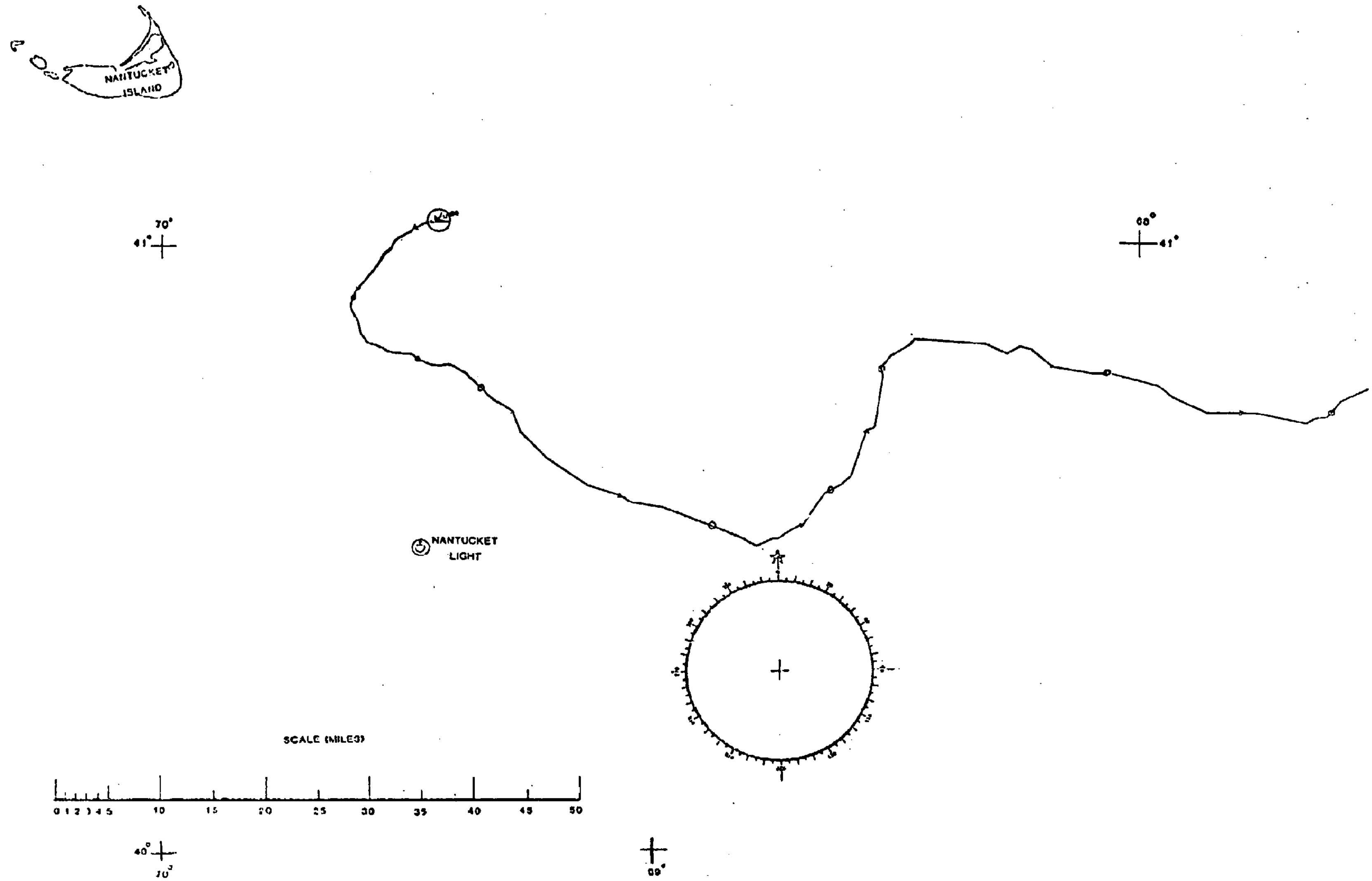


Figure VII-14. Progressive hourly wind vector diagram for 1600, December 15, to 0700, December 23, computed from 3.5°/o of the wind speed data.

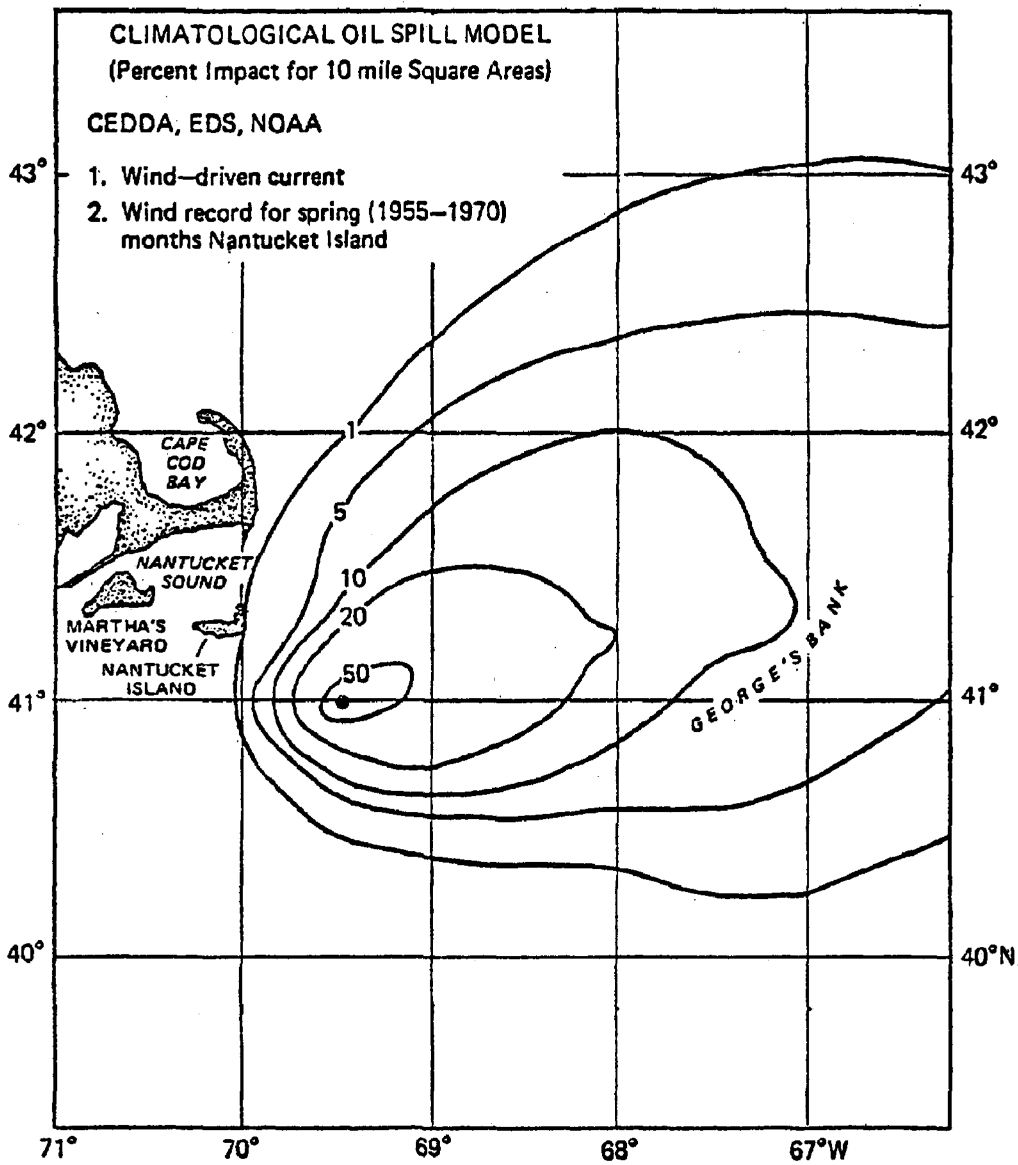


Figure VII-15. Impact probability for spring (no current).

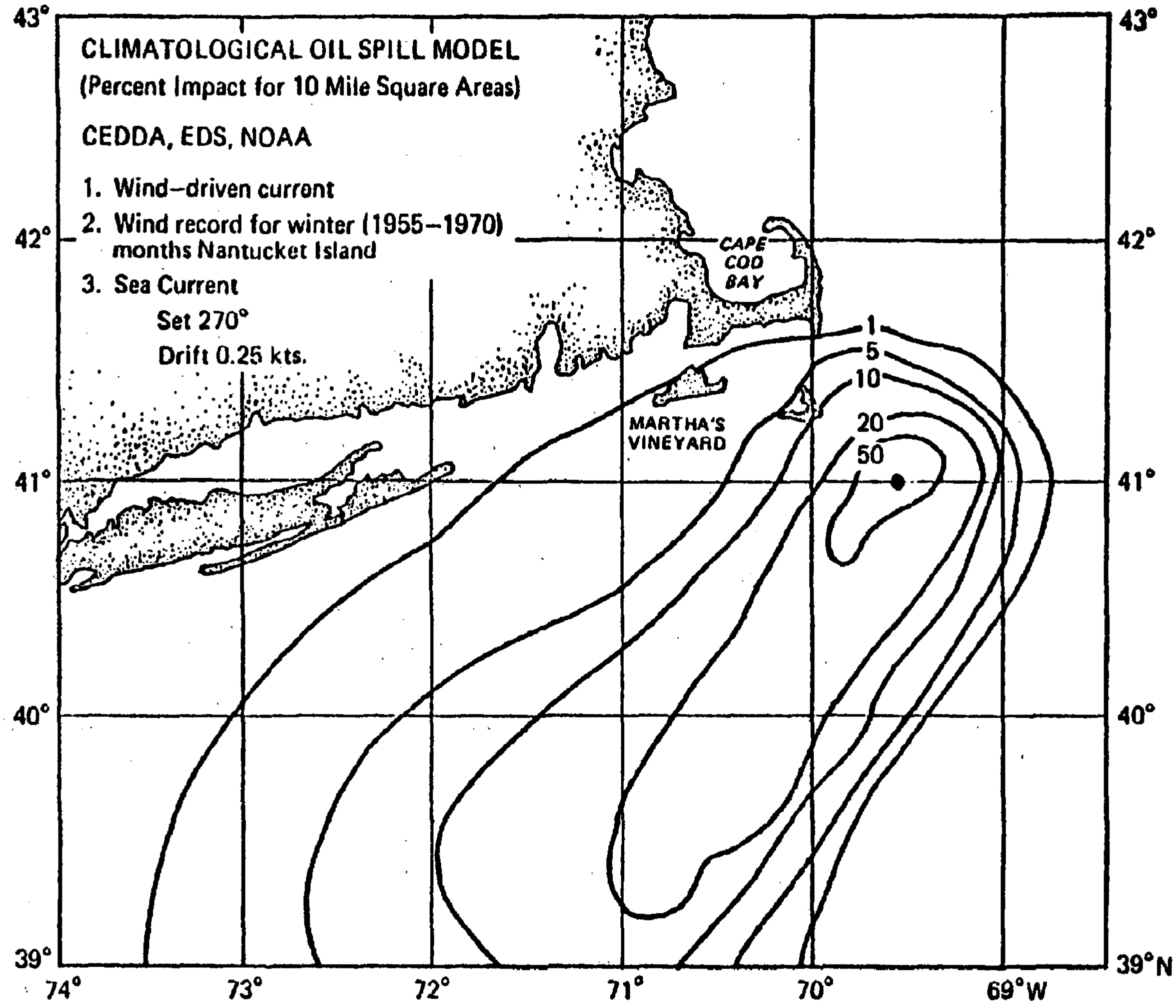


Figure VII-16. Impact probability for winter (winds and west current).

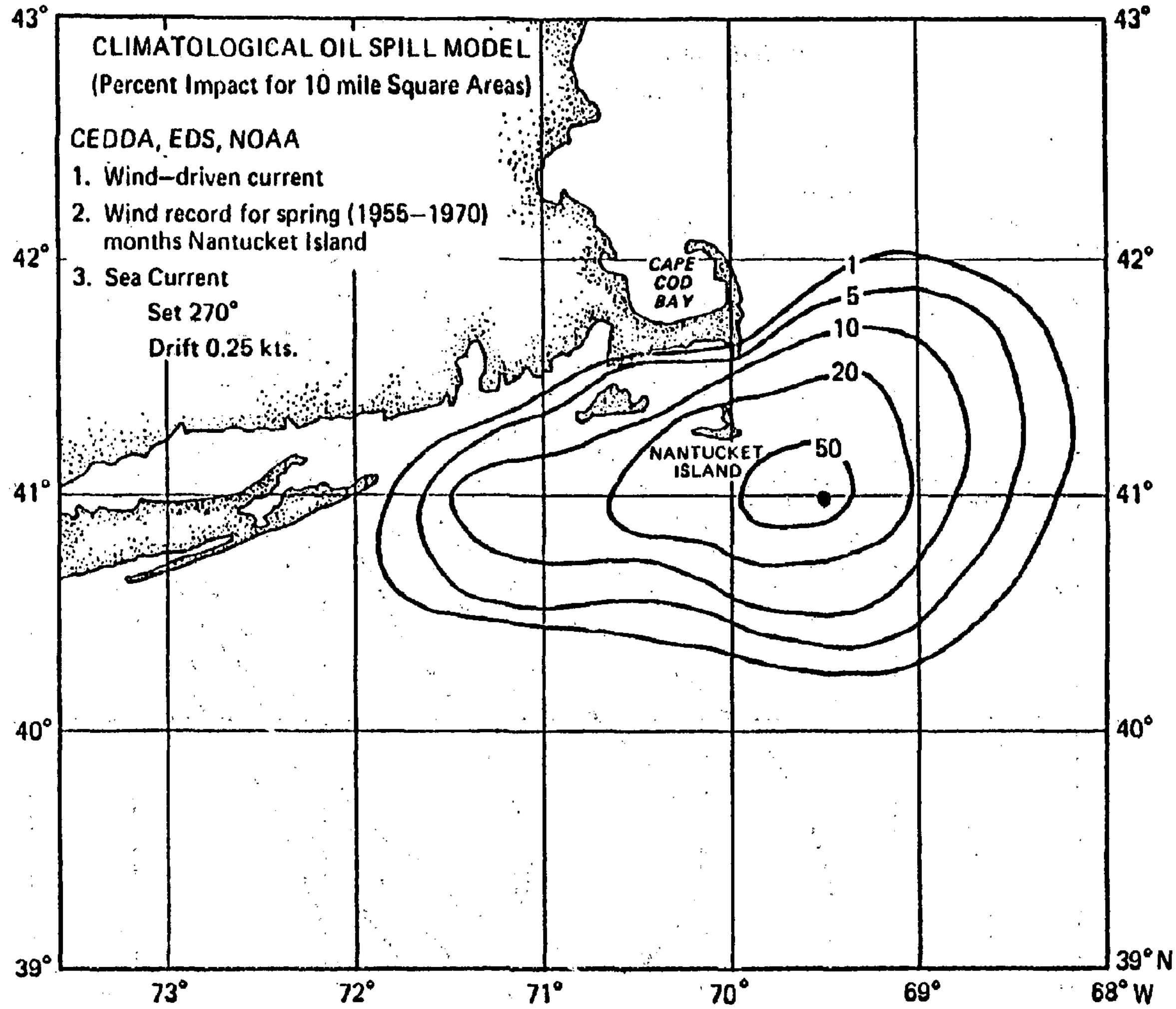


Figure VII-17. Impact probability for spring (winds and west current).

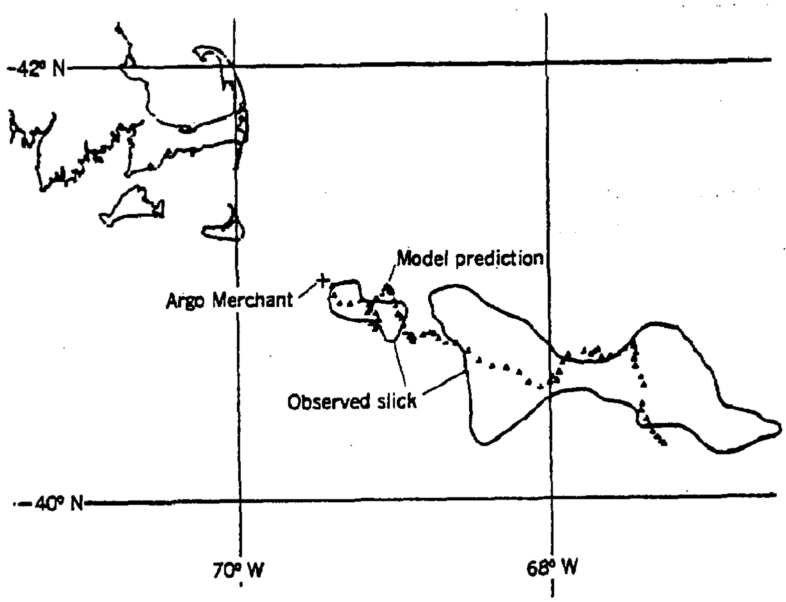


Figure VII-18. Predicted and observed location and shape of oil slick, December 27. Model prediction shows oil released from the *Argo Merchant* from 1600, December 17, through 1300, December 27. Wind input is from Nantucket Light Ship.

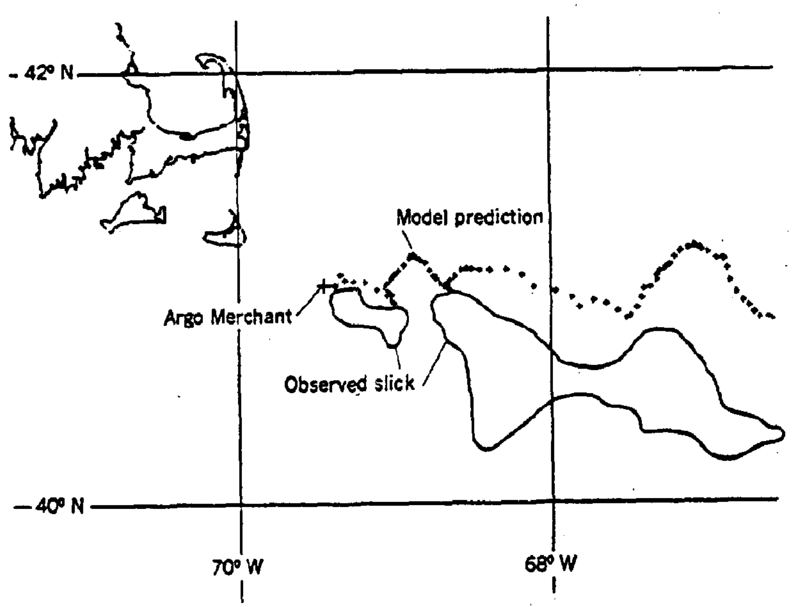


Figure VII-19. Predicted and observed location and shape of oil slick, December 27. Model prediction shows oil released from the *Argo Merchant* from 1600, December 27, through 1300, December 27. Wind input is from USCGC *Vigilant*.

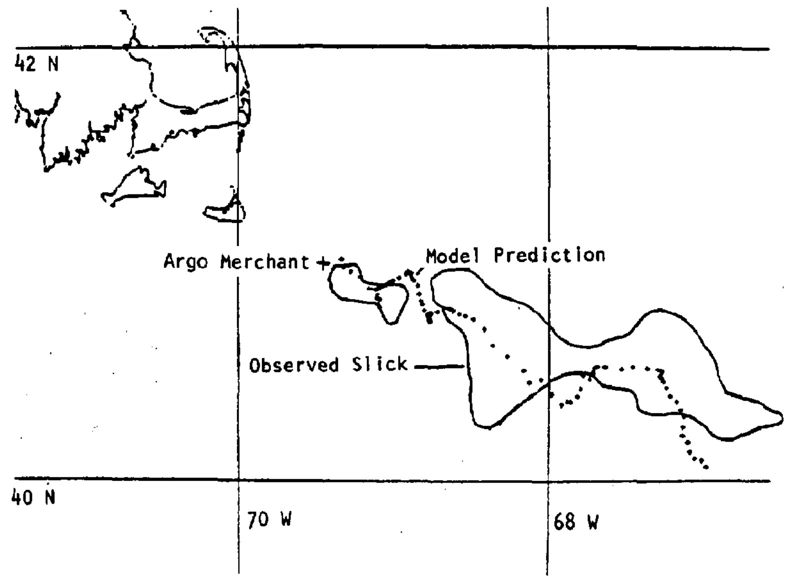


Figure VII-20. Predicted and observed location and shape of oil slick, December 27. Model prediction shows oil released from the *Argo Merchant* from 1600, December 17, through 1300, December 27. Wind input is from USCGC *Vigilant* with 20° drift angle added.

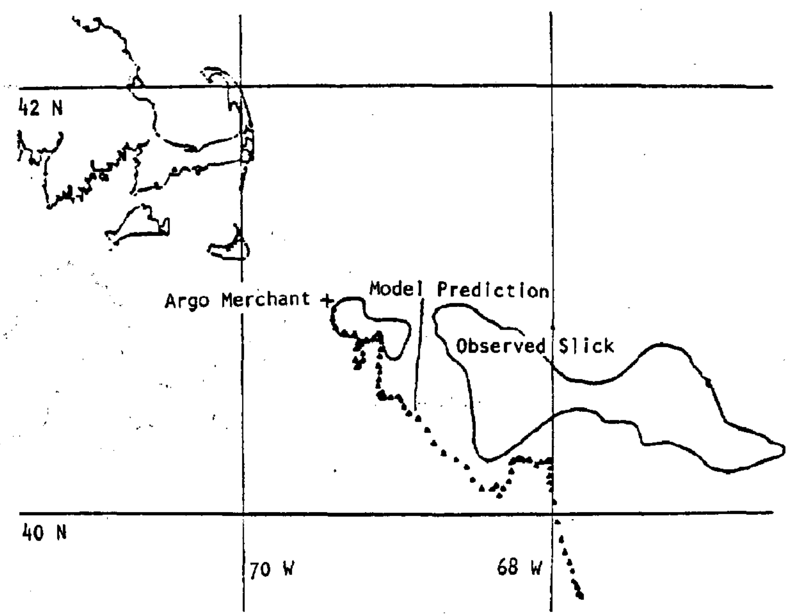


Figure VII-21. Predicted and observed location and shape of oil slick, December 27. Model prediction shows oil released from the *Argo Merchant* from 1600, December 17 through 1300, December 27. Wind input is from Nantucket Light Ship with 20° drift angle added.

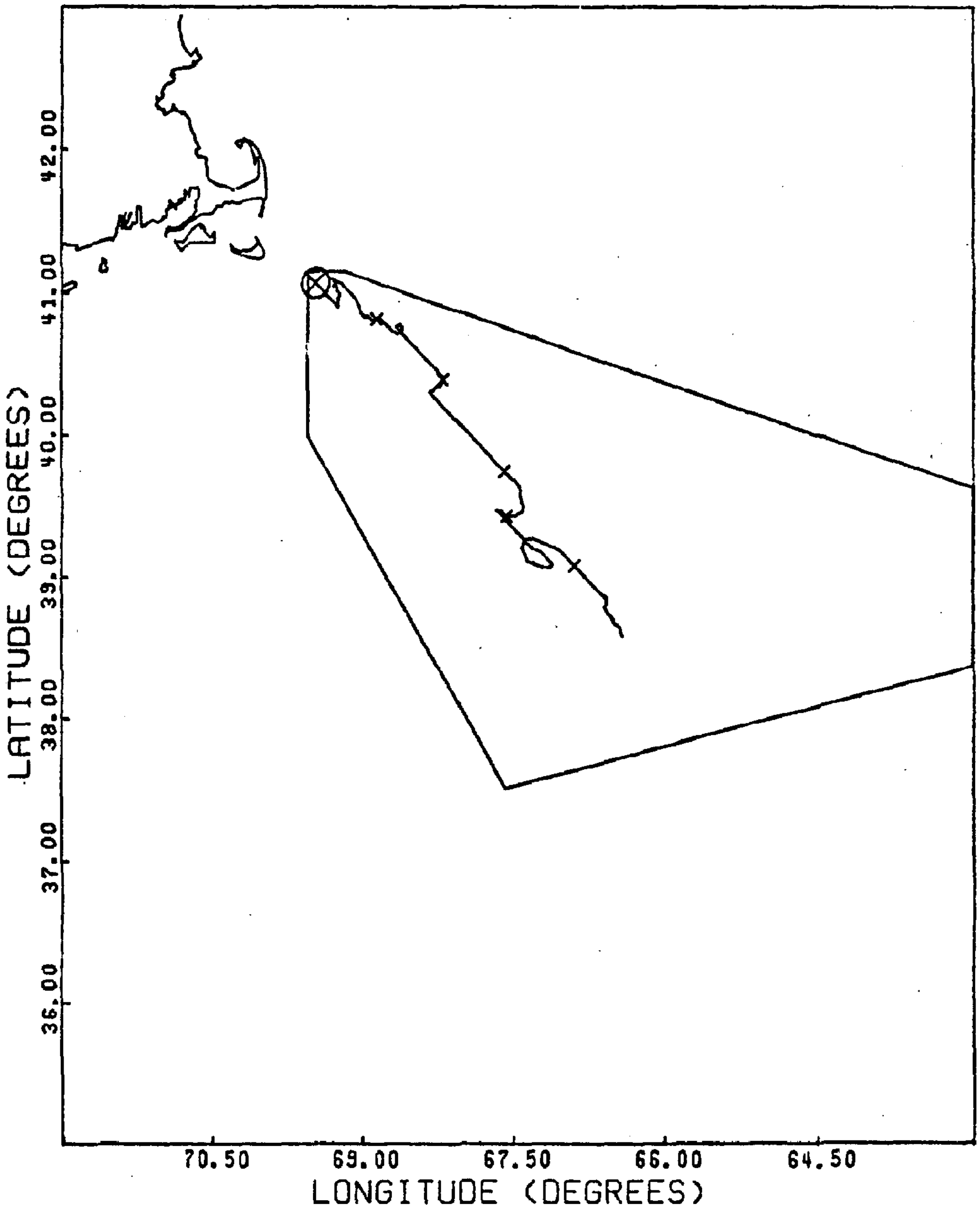


Figure VII-22. Thirty-day trajectory for the deterministic model (wind only).

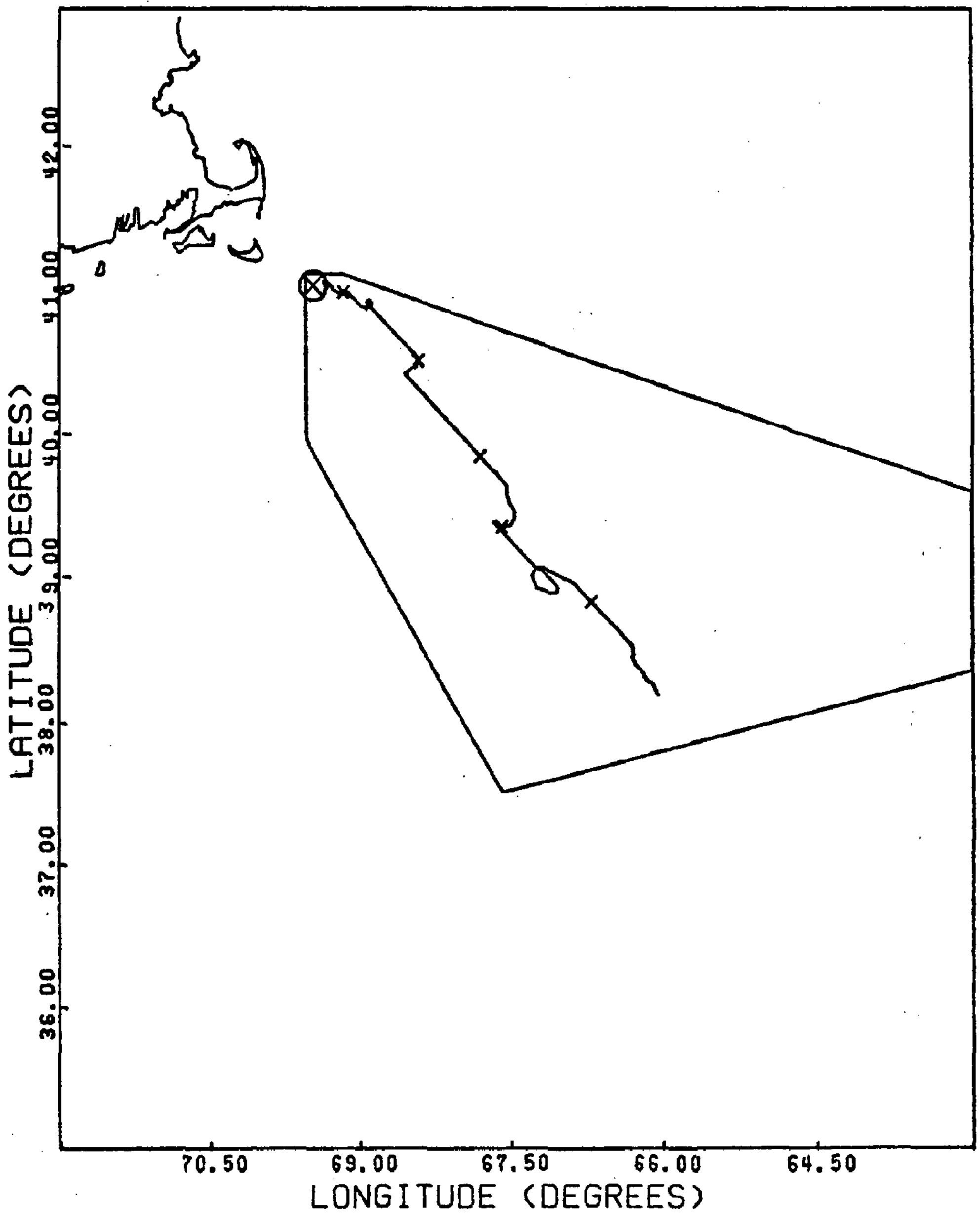


Figure VII-23. Thirty-day trajectory for the deterministic model (wind and tidal currents).

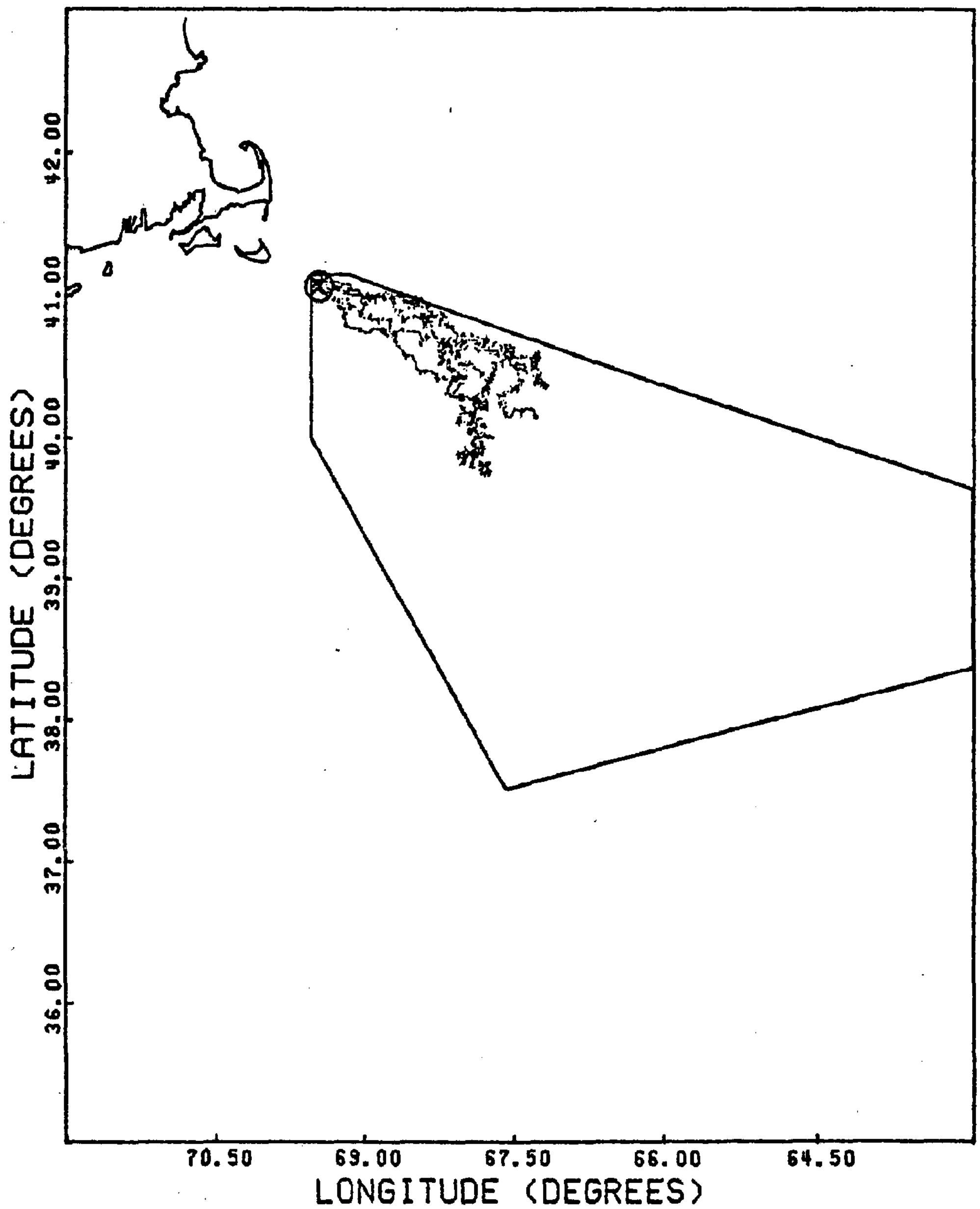


Figure VII-24. Five Monte Carlo trajectories of thirty days duration (wind only).

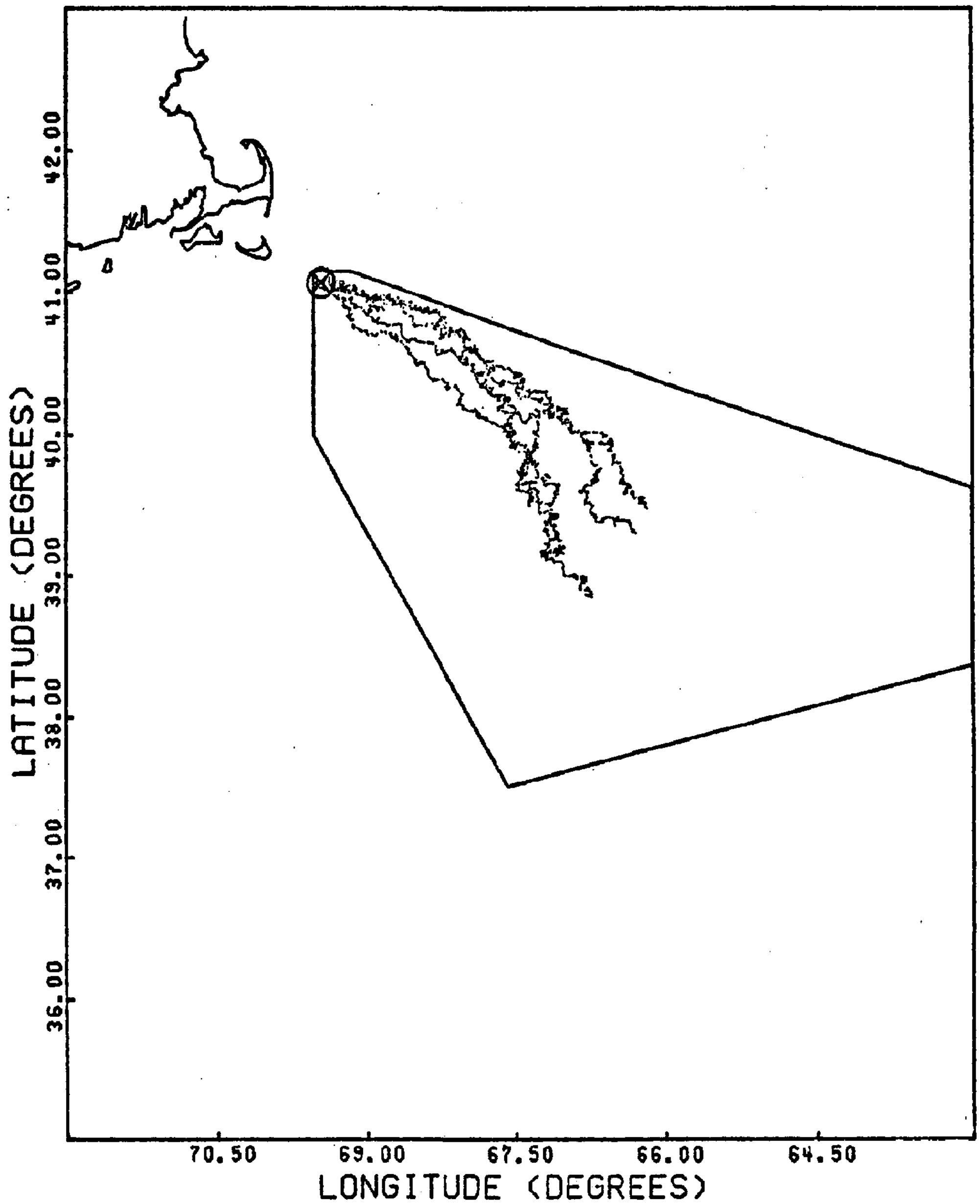


Figure VII-25. Five Monte Carlo trajectories of thirty days duration (wind and tidal currents).

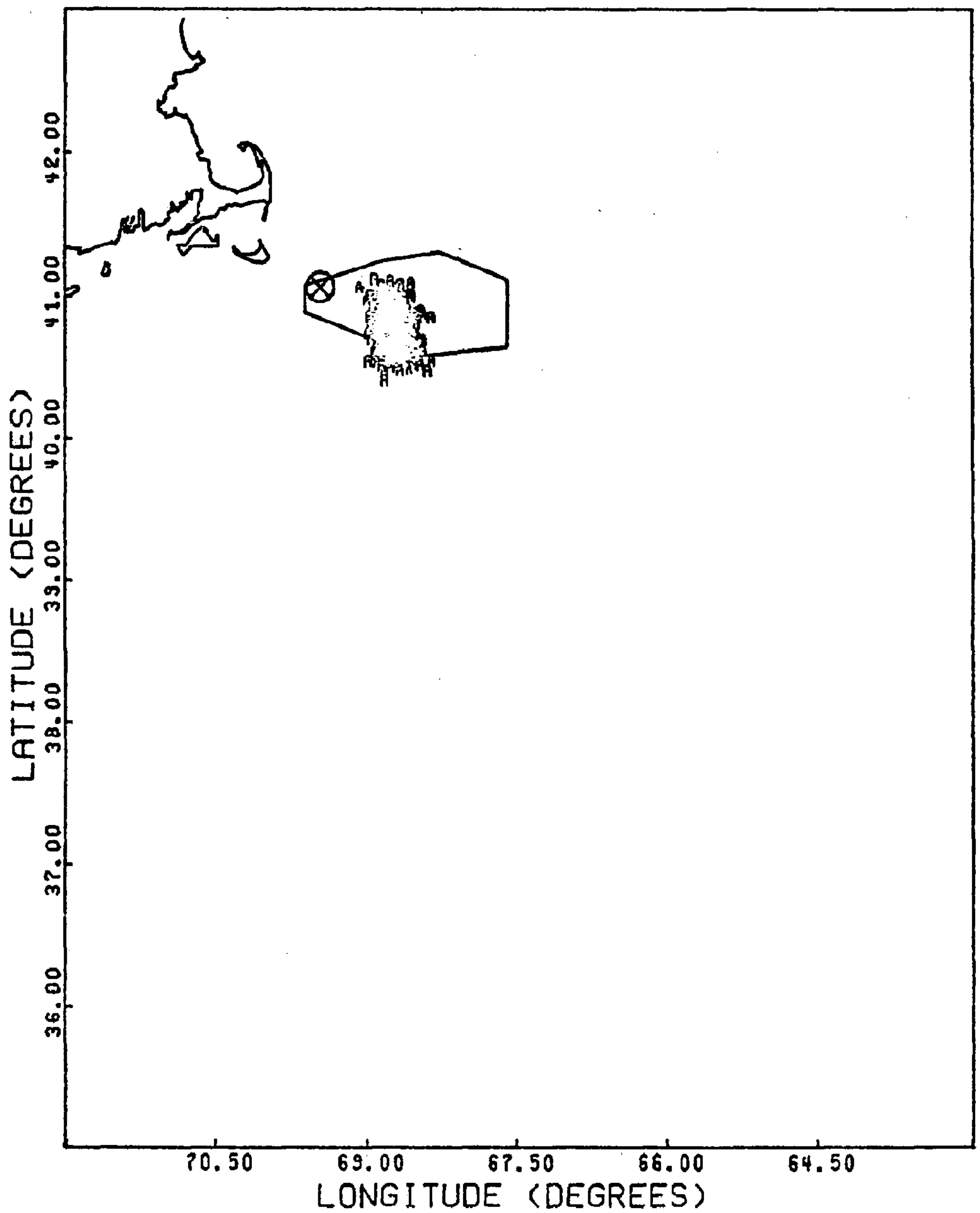


Figure VII-26. Five-day Monte Carlo prediction (wind and tidal currents).

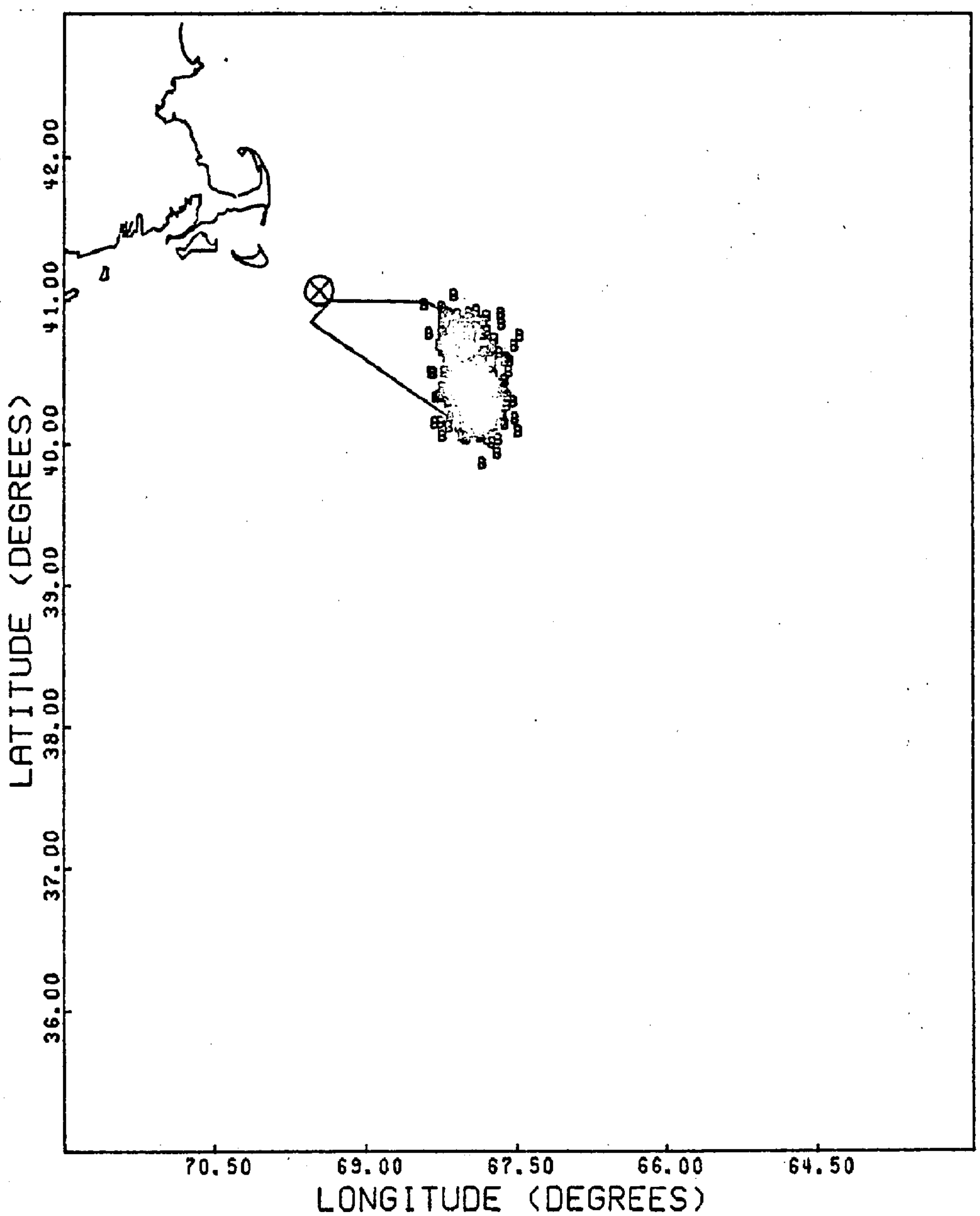


Figure VII-27. Ten-day Monte Carlo prediction (wind and tidal currents).

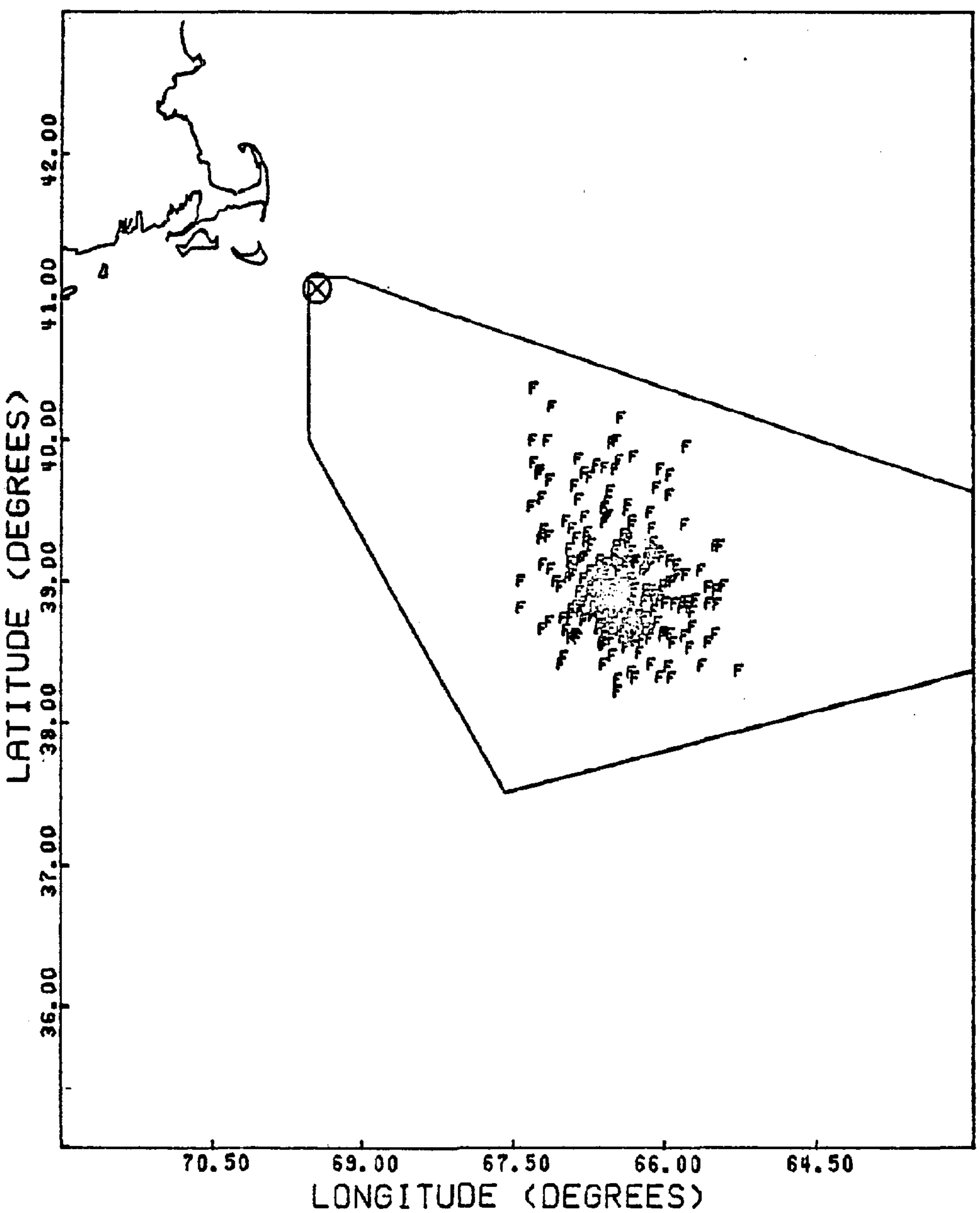


Figure VII-28. Thirty-day Monte Carlo prediction (wind and tidal currents).

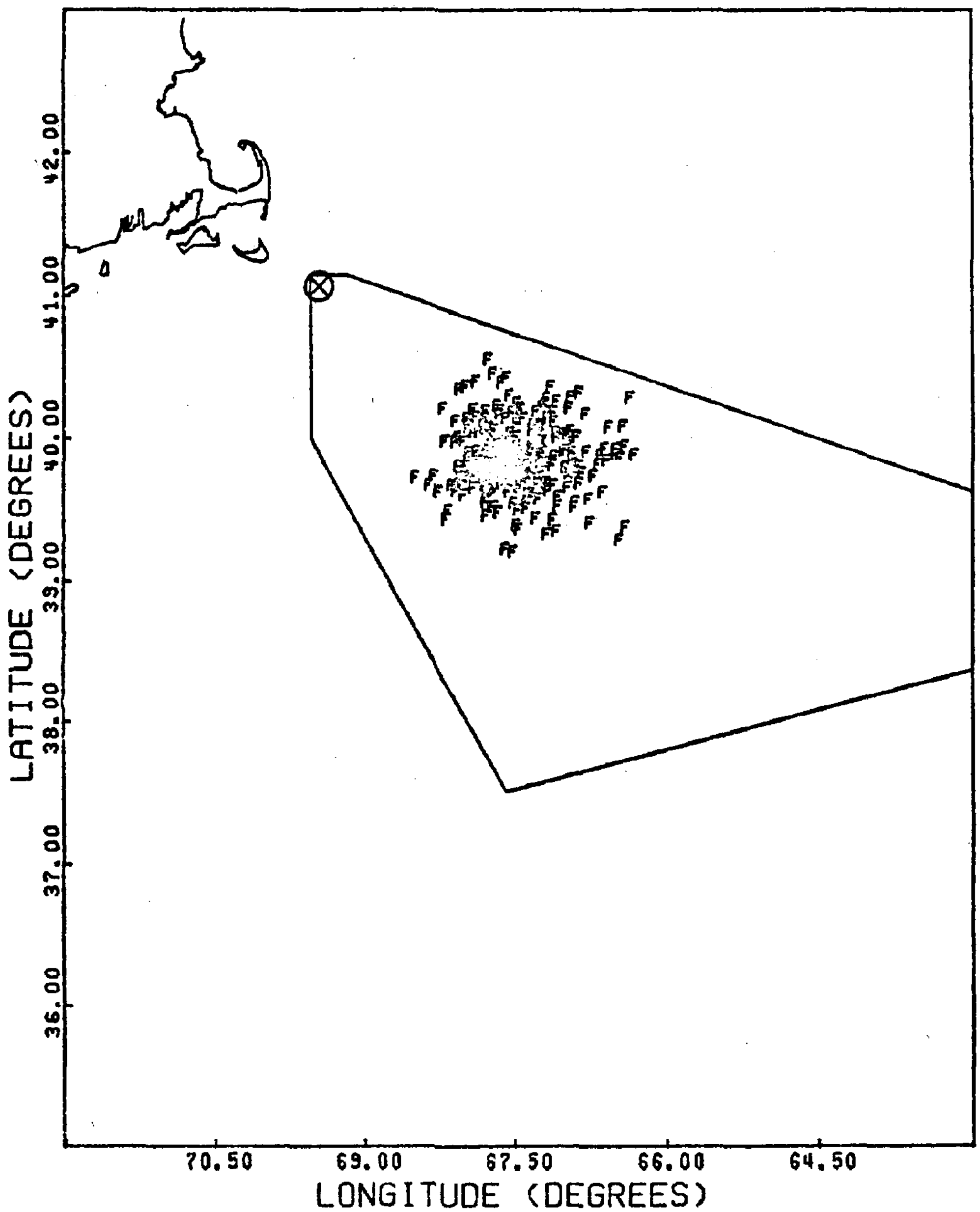


Figure VII-29. Thirty-day Monte Carlo prediction (wind only).

Table VII-1. Flight log, NASA C-54 overflight of *Argo Merchant* oil spill, December 19, 1976

Flight line	Altitude (ft)	Direction (°true)	Time (GMT) start stop	Lat. N start stop (min/deg)	Long. W start stop min/deg)
1	5500	175	14:42:40 -	41 01.2 -	61 27.8 -
2	5500	76	- -	40 59.5 -	69 24.5 -
3	5500	32	- -	41 01.2 -	69 21.0 -
4	5500	7	- -	41 01.1 -	69 28.9 -
5	5500	68	15:22:30 -	41 01.1 41 03.9	69 23.9 69 18.8
6	5500	275	15:28:52 15:31:59	41 02.3 41 01.1	69 19.7 69 29.2
7	5500	80	15:35:11 15:37:47	41 00.4 41 01.8	69 29.3 69 19.8
8	5500	252	15:41:30 15:44:18	40 59.9 40 58.0	69 20.7 69 28.9
9	2500	64	15:48:50 -	41 01.2 41 04.0	69 29.2 69 19.3
10	2500	203	15:54:50 15:57:08	41 04.1 40 58.9	69 19.3 69 21.6
11	2500	253	15:59:00 16:01:36	40 58.7 40 57.7	69 21.9 69 29.4
12	2500	17	16:03:40 16:04:46	40 58.9 41 01.8	69 30.0 69 28.7

T-11 Camera	Lenses	Type	Film (aerial film speed)	Filter	No. frames taken
1	6.3 in.	2443	40	1.2 anti-vignetting	198

Table VII-2. Flight log, NASA C-54 overflight of *Argo Merchant* oil spill, December 22, 1976

Flight line	Altitude (ft)	Time GMT start stop	Lat. N start stop (min/deg)	Long. W start stop (min/deg)
1	2500	17:12:00	41 02.0	69 27.5
		17:16:30	41 00.5	69 26.6
2	2500	17:16:30	41 01.8	69 27.3
		17:17:45	41 00.2	69 25.3
3	2500	17:17:45	40 59.8	69 24.0
		17:19:15	41 00.7	69 19.8
4	2500	17:19:15	41 00.7	69 19.8
		17:21:00	41 03.2	69 16.5
5	2500	17:21:00	41 05.5	69 14.9
		17:31:39	41 05.6	69 13.0
6	2500	17:31:39	41 02.2	69 27.8
		17:35:00	40 59.4	69 24.7
7	2500	17:35:00	40 59.3	69 25.1
		-	40 59.6	69 21.9
8	2500	-	40 59.6	69 21.9
		-	41 00.2	69 19.9
9	2500	-	41 00.2	69 19.9
		-	41 01.4	69 17.7
10	2500	-	41 01.4	69 17.7
		-	41 05.0	69 13.6
11	2500	17:45:00	41 02.1	69 28.1
		-	40 58.9	69 25.5
12	2500	17:48:30	40 58.8	69 24.6
		-	40 58.9	69 22.5
13	2500	-	40 58.9	69 22.5
		-	40 59.4	69 20.7
14	2500	-	40 59.4	69 20.7
		-	41 00.6	69 17.9
15	2500	-	41 00.6	69 17.9
		-	-	-

Table VII-2. Flight log, NASA C-54 overflight of *Argo Merchant* oil spill, December 22, 1976 (continued)

16	2500	-	41 03.3	69 14.6
17	2500	-	-	-
		-	41 04.7	69 13.4

T-11 Camera	Lenses	Type	Film Aerial Film Speed	Filter	Shutter Speed/sec	No frames Taken
1	6.3 inch	2443	40	1.2 anti-vignetting	1/75	172

Table VII-3. Flight log, NASA C-130 overflight of *Argo Merchant* oil spill, January 3, 1977

Flight line	Altitude (ft)	Time GMT start stop	Lat. N start stop (min/deg)	Long. W start stop (min/deg)
1	5600	16:18:30	39 57.3	66 20.7
		16:20:30	39 57.9	66 29.8
2	5300	16:22:05	40 00.9	66 28.7
		16:23:45	40 01.3	66 20.5
3	5000 to	16:26:55	40 02.0	66 21.4
	3800	16:28:35	39 57.3	66 24.1
4	3000	16:33:25	40 56.7	66 19.3
		16:42:30	39 52.1	66 56.6
5	3000	16:44:50	39 51.6	66 51.8
		16:50:24	39 55.7	66 22.1
5	3000	16:50:34	40 03.2	66 15.0
		16:53:55	40 01.9	66 19.0
6	5400	16:57:30	39 57.7	66 14.3
		16:58:25	39 55.9	66 01.8
7	5400	17:00:40	39 58.1	66 14.3
		17:03:20	39 58.2	66 01.8
8	5500	17:06:00	39 58.1	66 00.0
		17:09:25	39 58.2	66 14.4
9	3050	17:14:25	40 07.9	66 11.3
		17:15:25	40 08.9	66 13.8

Zeiss Camera	Lenses	Film Type/Emulsion		Filter	Shutter Speed/sec	F Stop ASA	No. Frames Taken
1	6 inch	S0397	48-1	Ratten 3	1/110	2/160	268
2	6 inch	2443	206-2	Ratten 12	1/110	2/80	259

Table VII-4. Flight log, NASA C-130 overflight of *Argo Merchant* oil spill, January 5, 1977

Flight line	Altitude (ft)	Time GMT start stop	Lat. N start stop (min/deg)	Long. W start stop (min/deg)
1	1900	15:48:35	41 01.2	69 29.8
		15:49:20	41 01.4	69 24.3
2	1900	15:52:50	40 59.9	69 25.3
		15:53:45	41 02.0	69 27.3
3	2000	15:57:25	41 01.8	69 27.5
		16:13:50	40 47.0	68 45.6

ZEISS Camera	Lenses	Film Type/Emulsion	Filter	Shutter Speed/sec	F Stop ASA	No. Frames Taken
1	6 inch	S0397 48-1	Ratten 3	1/100	2/160	253
2	6 inch	2443 206-2	Ratten 12	1/100	2/180	193

Table VII-5. Flight log, NASA C-54 overflight of *Argo Merchant* oil spill, January 6, 1977

Flight line	Altitude (ft)	Time GMT start stop	Lat. N start stop (min/deg)	Long. W start stop (min/deg)
1	2000	15:36:00 -	41 00.9 41 00.8	69 27.8 69 25.4
2	2000	18:45:00 -	41 00.0 41 02.8	69 28.1 69 27.8
3	2000	18:48:00 -	41 02.6 41 02.5	69 28.0 69 27.0

ZEISS Camera	Lenses	Film Type/Emulsion		Filter	Shutter Speed/sec	F Stop ASA	No. Frames Taken
1	6.3 inch	S0397	64	Haze No. 3	1/150		22
2	6.3 inch	2443	40	Clear anti-vignetting	1/75		23

Table VII-6. Tide tables for Nantucket Shoals

POLLOCK RIP CHANNEL, MASS., 1976

F-FLOOD, DIR. 035° TRUE E-EBB, DIR. 225° TRUE

NOVEMBER

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	VEL. KNOTS
1		0159	2.0F	16		0042	1.9F
M	0458	0758	1.6E	TU	0408	0644	1.7E
	1101	1433	1.9F		0958	1313	1.8F
	1723	2021	1.6E		1631	1908	1.7E
	2320				2216		
2		0258	2.1F	17		0139	2.0F
TU	0554	0857	1.7E	W	0501	0740	1.8E
	1153	1528	2.0F		1053	1413	1.9F
	1820	2123	1.6E		1727	2005	1.7E
					2314		
3	0017	0352	2.1F	18		0237	2.0F
W	0645	0948	1.7E	TH	0552	0833	1.9E
	1248	1617	2.1F		1146	1507	2.0F
	1911	2212	1.7E		1822	2100	1.8E
4	0107	0439	2.1F	19	0010	0330	2.1F
TH	0731	1033	1.8E	F	0643	0926	2.0E
	1332	1704	2.2F		1238	1601	2.2F
	1958	2255	1.7E		1915	2154	1.9E
5	0152	0522	2.1F	20	0104	0421	2.1F
F	0812	1112	1.8E	SA	0732	1017	2.1E
	1412	1743	2.2F		1328	1652	2.3F
	2040	2334	1.7E		2007	2249	2.0E
6	0232	0601	2.0F	21	0156	0512	2.2F
SA	0851	1146	1.8E	SU	0821	1108	2.2E
	1448	1825	2.2F		1418	1743	2.4F
	2120				2058	2338	2.0E
7		0007	1.7E	22	0248	0601	2.2F
SU	0310	0636	2.0F	M	0911	1156	2.2E
	0929	1216	1.8E		1507	1831	2.5F
	1523	1856	2.1F		2150		
	2159						
8		0040	1.7E	23		0031	2.0E
M	0346	0707	1.9F	TU	0340	0654	2.1F
	1006	1249	1.8E		1001	1247	2.2E
	1558	1927	2.1F		1557	1924	2.4F
	2237				2242		
9		0114	1.7E	24		0122	2.0E
TU	0423	0739	1.8F	W	0432	0745	2.0F
	1044	1324	1.8E		1053	1338	2.1E
	1633	1959	2.1F		1649	2017	2.4F
	2317				2336		
10		0151	1.7E	25		0216	1.9E
W	0501	0810	1.8F	TH	0527	0842	2.0F
	1123	1403	1.8E		1147	1431	2.0E
	1711	2034	2.1F		1743	2114	2.3F
	2359						
11		0232	1.7E	26	0031	0311	1.8E
TH	0542	0849	1.7F	F	0623	0943	1.9F
	1206	1444	1.8E		1244	1528	1.8E
	1752	2113	2.0F		1840	2215	2.2F
12	0043	0316	1.7E	27	0128	0411	1.7E
F	0627	0930	1.7F	SA	0723	1048	1.8F
	1252	1531	1.7E		1345	1631	1.7E
	1837	2158	2.0F		1940	2320	2.1F
13	0131	0403	1.6E	28	0227	0514	1.5E
SA	0715	1020	1.6F	SU	0824	1156	1.8F
	1343	1618	1.7E		1448	1736	1.5E
	1927	2247	1.9F		2042		
14	0222	0454	1.6E	29		0025	2.0F
SU	0807	1115	1.6F	M	0325	0618	1.6E
	1437	1713	1.6E		0926	1259	1.8F
	2021	2342	1.9F		1550	1841	1.5E
					2144		
15	0314	0549	1.6E	30		0126	2.0F
M	0902	1214	1.7F	TU	0423	0723	1.6E
	1533	1809	1.6E		1026	1400	1.9F
	2118				1651	1947	1.5E
					2245		

DECEMBER

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	VEL. KNOTS
1		0224	2.0F	16		0102	1.9F
W	0518	0818	1.6E	TH	0426	0705	1.8E
	1122	1455	2.0F		1019	1338	1.9F
	1749	2046	1.5E		1659	1935	1.7E
	2341				2244		
2		0319	2.0F	17		[illegible]	1.9F
TH	0609	0912	1.7E	F	0522	0804	1.8E
	1213	1549	2.0F		1118	1441	2.0F
	1841	2137	1.6E		1758	2036	1.7E
					2345		
3	0033	0406	2.0F	18		0307	1.9F
F	0656	0957	1.7E	SA	0617	0903	1.9E
	1259	1634	2.1F		1215	1542	2.1F
	1930	2224	1.6E		1857	2136	1.8E
4	0121	0451	2.0F	19	0045	0405	2.0F
SA	0740	1038	1.8E	SU	0711	0958	2.0E
	1341	1715	2.2F		1310	1640	2.3F
	2014	2305	1.6E		1953	2234	1.8E
5	0204	0532	1.9F	20	0142	0502	2.0F
SU	0821	1115	1.8E	M	0804	1052	2.0E
	1420	1756	2.2F		1403	1734	2.4F
	2056	2343	1.6E		2046	2328	1.9E
6	0244	0609	1.9F	21	0237	0556	2.0F
M	0901	1150	1.8E	TU	0856	1144	2.1E
	1457	1831	2.2F		1455	1827	2.4F
	2135				2139		
7		0018	1.7E	22		0021	1.9E
TU	0322	0642	1.8F	W	0329	0649	2.0F
	0939	1224	1.8E		0947	1236	2.1E
	1532	1904	2.2F		1546	1918	2.4F
	2214				2230		
8		0052	1.7E	23		0112	1.9E
W	0359	0715	1.8F	TH	0421	0741	2.0F
	1017	1259	1.8E		1038	1326	2.0E
	1608	1935	2.2F		1637	2008	2.4F
	2253				2320		
9		0129	1.7E	24		0203	1.9E
TH	0437	0748	1.8F	F	0512	0832	2.0F
	1057	1336	1.9E		1130	1416	1.9E
	1646	2007	2.2F		1727	2101	2.3F
	2333						
10		0206	1.8E	25	0011	0253	1.8E
F	0517	0823	1.8F	SA	0604	0925	1.9F
	1138	1417	1.9E		1224	1508	1.8E
	1725	2046	2.2F		1819	2153	2.2F
11	0015	0249	1.8E	26	0102	0346	1.7E
SA	0559	0904	1.8F	SU	0656	1021	1.8F
	1222	1502	1.9E		1319	1602	1.7E
	1809	2127	2.1F		1912	2247	2.1F
12	0059	0334	1.8E	27	0155	0441	1.7E
SU	0644	0947	1.9F	M	0751	1121	1.8F
	1310	1550	1.8E		1416	1658	1.6E
	1856	2215	2.1F		2007	2348	1.9F
13	0147	0425	1.8E	28	0248	0537	1.6E
M	0733	1038	1.8F	TU	0847	1220	1.8F
	1403	1641	1.8E		1515	1801	1.5E
	1947	2304	2.0F		2105		
14	0238	0513	1.8E	29		0044	1.5F
TU	0826	1135	1.8F	W	0343	0633	1.6E
	1459	1736	1.7E		0943	1317	1.8F
	2043				1614	1902	1.4E
					2203		
15		0003	2.0F	30		0143	1.8F
W	0331	0610	1.3E	TH	0437	0731	1.5E
	0922	1235	1.8F		1039	1419	1.9F
	1558	1835	1.7E		1712	2002	1.4E
	2143				2301		
				31		0238	1.8F
				F	0530	0828	1.6E
					1133	1512	1.9F
					1807	2058	1.4E
					2356		

TIME MERIDIAN 75° W. 0000 IS MIDNIGHT, 1200 IS NOON.

Table VII-7. Current meter deployments

Key agency	Date	Duration (days)	Location Lat. N (deg/min)	Long. W	Instruments/Depth
121 USGS	12/28/76	60	40 53.4	69 09.6	Tripod at 85 m VCAMS at 45 and 75 m
123 USGS	12/28/76	60	40 14.0	69 22.5	VCAM at 13 m
124 USGS	12/28/76	60	40 42.5	70 00.5	Tripod at 70
X USGS	12/28/76	60	40 30.8	69 29.3	850 at 18 m
Z NUSC	2/29/76	50	40 50.5	69 16	3 current meters
1 USGS	12/05/76	60	40 51.2	67 24.7	EGG EM at 18 and 28 m
A NOS	8/19/60		41 02.7	69 46.6	3, 10 and 16 m
B NOS	8/19/60	7	41 01.9	69 43.4	8, 19 and 34 m
C NOS	8/19/60	5	41 02.1	69 41.4	Robert at 2.5, 7 and 12 m
23 NOS	2/- /33	1/2	41 19.3	69 21	Unknown
32 NOS	2/- /33	1	40 58.4	69 30	Unknown
36 NOS	2/- /33	2	41 07	69 41.4	Unknown

Table VII-8. Lagrangian Drifters

ID	Date	Local Time	Position Lat. N	Position Long. W	Time (hr)	Speed (kt)	Dir. (°true)
DMB 1 a	12/18/76	1041	41 02	69 27.5			
b	12/18/76	1340	40 59.5	69 30.0	2.9	.91	142
c	12/19/76	0910	40 53.1	69 14.9	22.5	.58	119
d	12/20/76	1023	40 56.4	69 08.5	22.2	.26	56
DMB 2 a	12/27/76	1020	40 44.0	68 20.3			
b	12/31/76	1200	40 29.0	68 00.0	98	.22	135
DMB 3 a	12/31/76	1340	40 07	66 59	8.6	1.45	132
b	12/31/76	2217	39 57.6	66 46.8			
DMB 4 a	1/18/77	1400	41 02	69 28			
b	1/19/77	1440	40 55	69 15.5	24.7	.48	126
DMB 5 a	1/23/77	1018	41 02	69 27.5			
b	1/26/77	0930	40 50.3	69 25.9	23.2	.51	174
PW 1	12/18/76	1348	41 02.0	69 27.5			
PW 2	12/18/76	1352	41 02.0	69 27.5			
	2/2/77	0715	40 21	70 59			
PW 3	12/18/76	1353	41 02.0	69 27.5			
PW 4	12/30/76	1000	40 42.5	69 26.0			

Table VII-9. Drift card deployments

Deployment No.	Date	Time	Location Lat. N (deg/min)	Long. W	Quantity
1	12/21/76	1615	41 02	69 27.5	500
2	12/26/76	0947	41 065	69 52.0	1000
3	12/26/76	954	41 15.8	69 47.0	1000
4	12/26/76	1000	41 21.3	69 30.0	980
5	12/26/76	1220	41 01.1	68 40.4	100
6	12/27/76	902	41 25.0	69 50.0	1000
7	12/27/76	912	41 15.0	69 50.0	1000
8	12/27/76	1000	41 07.0	70 00.0	1000
9	12/30/76	1041	40 30.0	70 30.0	1000
10	12/30/76	1102	34 45.0	70 03.0	1000
11	12/30/76	1245	40 12.3	67 01.6	1000
12	1/3/77	1200	41 4.5	69 34.0	1000

Table VII-10. NOAA drifting buoy 343

DAY	YR	HOUR	LAT-N D	LAT-N M	LONG-W D	LONG-W M	DIST NM	TIME MIN	SPEED KTS	DIR T
31	76	2217	39	57	66	46				
1	76	154	39	55	66	42	4.0	216	1.1	126
1	77	836	39	51	66	33	8.4	401	1.3	119
1	77	1020	39	48	66	40	6.6	104	3.8	243
1	77	12 7	39	49	66	30	7.8	106	4.4	81
1	77	2137	39	42	66	27	7.7	570	.8	159
1	77	2322	39	41	66	26	.8	104	.4	142
2	77	757	39	34	66	24	7.3	514	.9	169
2	77	939	39	32	66	24	1.8	101	1.1	179
2	77	2240	39	25	66	26	7.3	780	.6	190
2	77	2429	39	23	66	25	1.9	108	1.0	165
3	77	215	39	22	66	23	1.9	105	1.1	108
3	77	858	39	21	66	30	5.6	402	.8	257
3	77	2159	39	19	66	31	2.6	780	.2	200
4	77	131	39	18	66	33	1.8	211	.5	228
4	77	818	39	18	66	37	3.2	406	.5	280
4	77	10 1	39	18	66	41	2.8	103	1.6	257
4	77	2119	39	14	66	52	9.0	677	.8	246
4	77	23 3	39	14	66	52	.5	103	.3	270
5	77	742	39	0	66	57	14.2	518	1.6	193
5	77	920	39	3	67	3	5.6	97	3.4	295
5	77	24 8	38	54	67	12	10.6	887	.7	217
6	77	841	38	49	67	25	11.5	512	1.3	245
6	77	1024	38	46	67	35	7.9	103	4.6	247
6	77	1212	38	47	67	28	5.1	107	2.8	83
6	77	2330	38	43	67	38	8.4	678	.7	240
7	77	8 1	38	43	67	41	2.3	510	.3	270
7	77	942	38	42	67	43	1.9	101	1.1	251
7	77	2246	38	45	67	41	3.0	783	.2	37
8	77	9 3	38	31	67	34	14.1	616	1.4	159
8	77	2349	38	24	67	18	14.6	885	1.0	122
9	77	822	38	19	66	59	15.2	512	1.8	106
9	77	10 5	38	20	66	55	2.8	103	1.6	77
9	77	2123	38	24	66	18	28.6	677	2.5	81
9	77	23 8	38	26	66	14	3.7	105	2.1	60
10	77	746	38	35	66	4	11.6	517	1.3	39
10	77	924	38	34	65	58	4.7	97	2.9	104
10	77	2412	38	50	65	45	19.3	887	1.3	32
11	77	2 2	38	51	65	45	1.3	110	.7	339
11	77	844	38	49	65	37	6.8	401	1.0	110
11	77	2146	38	45	65	24	10.9	781	.8	112
12	77	120	38	42	65	18	5.2	213	1.4	117

Table VII-10. NOAA drifting buoy 343 (continued)

DAY	YR	HOUR	LAT-N D	M	LONG-W D	M	DIST NM	TIME MIN	SPEED KTS	DIR T
12	77	8 6	38	37	65	11	7.4	405	1.1	137
12	77	947	38	36	65	10	1.5	101	.9	142
12	77	21 8	38	30	64	46	19.0	681	1.7	106
12	77	2252	38	30	64	43	2.4	104	1.4	104
13	77	9 6	38	23	63	54	38.0	613	3.7	100
14	77	825	38	18	61	43	99.1	1398	4.3	93
14	77	1010	38	21	61	30	10.9	105	6.2	74
14	77	1158	38	22	61	30	1.3	107	.7	339
14	77	2128	38	34	61	4	23.0	570	2.4	58
15	77	1 1	38	39	60	58	6.9	212	2.0	46
15	77	746	38	57	60	54	18.8	405	2.8	6
15	77	927	38	48	60	44	12.3	101	7.3	141
15	77	2049	38	57	60	24	17.8	682	1.6	57
16	77	846	38	54	60	21	3.8	716	.3	142
16	77	2150	38	45	60	11	11.9	784	.9	139
16	77	2334	38	45	60	7	2.7	103	1.6	89
17	77	122	38	43	60	22	11.1	107	6.2	260
17	77	8 8	38	46	60	3	14.3	405	2.1	80
17	77	950	38	43	60	1	2.8	101	1.6	150
17	77	2252	38	42	59	54	5.8	781	.4	108
17	77	2442	38	42	59	52	1.4	109	.7	89
18	77	732	38	45	59	55	4.3	409	.6	327
18	77	9 8	38	45	59	49	4.6	96	2.9	97
18	77	2358	38	51	59	48	6.1	889	.4	8
19	77	829	38	46	59	46	4.4	510	.5	161
19	77	2130	38	49	59	53	5.8	780	.4	300
19	77	2316	38	48	59	51	2.3	105	1.3	142
20	77	750	38	39	59	45	9.6	513	1.1	151
20	77	938	38	39	59	45	.6	108	.3	179
20	77	2235	38	37	59	37	6.0	777	.5	101
21	77	852	38	30	59	37	7.2	616	.7	179
21	77	2339	38	24	59	40	6.3	886	.4	196
22	77	811	38	21	59	46	6.2	511	.7	234
22	77	955	38	16	60	3	13.6	104	7.9	249
22	77	1144	38	18	59	47	12.4	108	6.8	81
22	77	2113	38	7	59	49	10.9	569	1.1	187
23	77	735	37	54	59	52	12.8	621	1.2	190
23	77	914	37	51	59	51	3.0	98	1.8	171
23	77	24 4	37	31	59	46	20.2	890	1.4	168
24	77	833	37	22	59	43	9.8	508	1.2	169
24	77	2135	37	12	59	40	10.6	782	.8	164
25	77	110	37	9	59	37	3.0	214	.8	142

Table VII-11. NOAA drifting buoy 373

DAY	YR	HOUR	LAT-N		LONG-W		DIST	TIME	SPEED	DIR
			D	M	D	M	NM	MIN	KTS	T
27	76	2137	40	36	74	2				
27	76	2322	40	42	74	1	5.4	104	3.1	4
28	76	935	40	41	74	1	.6	612	.1	179
28	76	2239	40	3	72	24	83.0	784	6.4	117
29	76	854	39	38	70	55	72.5	614	7.1	110
29	76	1037	39	30	70	46	10.1	102	5.9	140
29	76	1228	39	29	70	31	11.5	110	6.2	96
29	76	2156	39	26	70	29	3.5	568	.4	148
30	76	616	39	22	70	24	5.1	619	.5	134
30	76	959	39	21	70	25	1.9	102	1.1	194
30	76	23 4	39	19	70	18	5.2	785	.4	103
31	76	11 1	39	20	70	13	3.7	716	.3	80
31	76	2220	39	17	70	18	4.4	679	.4	226
1	77	150	39	16	70	33	11.5	209	3.3	263
1	77	837	39	14	70	11	16.5	406	2.4	96
1	77	1020	39	15	70	17	4.7	103	2.7	284
1	77	2138	39	7	70	11	9.6	677	.8	151
1	77	2325	39	4	70	10	2.6	106	1.4	159
2	77	943	39	0	70	9	4.9	617	.5	169
2	77	2241	38	53	70	3	7.8	778	.6	148
3	77	9 0	38	54	70	7	3.0	618	.3	293
3	77	1044	38	55	69	59	6.0	103	3.5	78
3	77	22 2	38	51	70	7	7.6	678	.7	236
4	77	135	38	52	70	10	2.2	212	.6	303
4	77	820	38	53	70	15	3.7	405	.5	279
4	77	10 0	38	51	70	12	3.3	100	2.0	136
4	77	23 3	38	46	70	23	9.6	782	.7	244
5	77	924	38	39	70	31	9.8	620	.9	217
5	77	2411	38	32	70	34	7.1	886	.5	202
6	77	842	38	28	70	39	4.8	510	.6	221
6	77	1026	38	28	70	39	.8	103	.4	217
6	77	2330	38	25	70	37	3.0	784	.2	142
7	77	945	38	24	70	33	3.0	614	.3	113
7	77	2246	38	21	70	18	12.0	780	.9	107
8	77	9 3	38	11	70	9	12.1	616	1.2	142
8	77	1048	38	11	69	56	9.6	105	5.5	89
8	77	1239	38	7	70	4	7.6	111	4.1	236
8	77	2355	38	12	69	34	23.3	676	2.1	78
9	77	2317	38	20	67	24	99.8	1402	4.3	85
10	77	925	38	30	66	37	36.8	607	3.6	74
10	77	2416	38	47	66	18	22.7	891	1.5	39
11	77	845	38	43	66	8	8.1	508	1.0	116

Table VII-11. NOAA drifting buoy 373 (continued)

DAY	YR	HOUR	LAT-N D	LAT-N M	LONG-W D	LONG-W M	DIST NM	TIME MIN	SPEED KTS	DIR T
11	77	1029	38	41	66	1	6.0	104	3.4	113
11	77	1221	38	41	65	58	2.3	111	1.2	89
11	77	2145	38	40	65	39	14.1	564	1.5	92
12	77	120	38	37	65	31	6.6	214	1.9	116
12	77	8 7	38	36	65	18	10.1	406	1.5	96
12	77	947	38	35	65	16	1.8	100	1.1	131
12	77	21 6	38	17	64	43	31.2	679	2.8	125
12	77	2251	38	27	64	34	12.3	105	7.0	33
13	77	910	38	22	63	41	40.4	618	3.9	96
14	77	142	38	13	62	9	70.4	991	4.3	97
14	77	827	38	15	61	39	23.4	405	3.5	84
14	77	10 9	38	19	61	30	7.7	101	4.5	62
14	77	12 0	38	19	61	21	6.9	111	3.7	84
14	77	2129	38	31	61	3	17.9	569	1.9	47
15	77	1 1	38	34	60	57	5.5	211	1.5	56
15	77	746	38	39	60	45	10.7	405	1.6	63
15	77	928	38	41	60	42	2.6	101	1.5	45
16	77	848	38	36	60	24	14.7	1399	.6	111
16	77	2150	38	31	60	22	4.4	782	.3	161
16	77	2337	38	31	60	20	1.9	106	1.1	108
17	77	8 8	38	19	60	27	13.0	510	1.5	202
17	77	2256	38	35	60	5	23.1	887	1.6	45
17	77	2443	38	34	60	4	.8	106	.4	142
18	77	731	38	37	60	6	2.6	408	.4	339
18	77	911	38	35	59	58	6.2	99	3.7	106
18	77	24 0	38	43	59	48	11.0	889	.7	44
19	77	832	38	41	59	47	1.9	511	.2	165
19	77	2136	38	28	59	55	14.1	784	1.1	206
20	77	752	38	36	59	40	13.9	615	1.4	58
20	77	932	38	34	59	42	2.2	100	1.3	236
20	77	2235	38	33	59	33	7.1	783	.5	104
21	77	851	38	22	59	36	10.4	615	1.0	190
21	77	2343	38	12	59	38	11.0	892	.7	189
22	77	812	38	6	59	43	7.0	509	.8	211
22	77	1147	37	58	59	42	7.8	214	2.2	176
22	77	2115	37	45	59	42	13.2	568	1.4	178
23	77	916	37	28	59	40	16.9	720	1.4	175
23	77	24 5	37	8	59	33	20.5	888	1.4	164
24	77	855	37	0	59	30	8.1	529	.9	163
24	77	2136	36	51	59	24	9.9	761	.8	155
25	77	1 9	36	49	59	24	1.9	212	.5	165

Table VII-12. Wind direction (true) and wind speed at the *Argo Merchant* site (°/kn)

Time	December 1976																
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0100	195/30	080/12	020/22	320/25	295/20	240/20	220/23	285/50	225/20	305/18	270/10	240/10	280/32	295/30	100/12	285/40	280/20
0200	195/36	060/14	350/23	310/25	295/20	240/15	220/20	285/45	220/20	310/19	290/10	230/5	260/30	295/25	110/12	280/40	280/15
0300	175/35	070/15	330/23	300/25	290/14	230/13	240/20	290/45	250/20	315/18	300/7	145/10	280/35	285/26	110/12	280/40	300/08
0400	185/40	070/20	335/20	300/25	295/15	230/11	240/10	310/47	245/18	317/18	300/6	150/10	280/26	275/19	090/15	280/40	300/08
0500	200/36	068/11	345/20	340/26	295/15	199/8	245/13	295/45	245/19	295/17	295/6	145/15	300/20	289/165	100/15	280/35	350/05
0600	215/34	070/15	340/19	340/30	300/15	230/11	240/19	295/48	235/15	305/15	210/6	130/13	310/23	280/07	110/23	280/35	310/10
0700	230/34	070/15	335/19	310/30	295/10	210/11	220/20	290/42	245/9	315/13	220/8	135/12	320/22	286/08	110/25	280/35	300/10
0800	230/23	030/8	290/20	315/30	300/10	190/10	270/25	290/30	240/5	315/20	220/16	135/10	290/27	Calm	110/25	280/35	300/10
0900	230/25	060/18	300/22	320/40	310/10	200/10	280/25	270/30	240/1	320/18	230/18	150/15	290/30	060/05	110/25	280/40	300/10
1000	240/20	056/16	295/19	310/40	300/10	200/10	270/30	270/25	190/5	320/20	230/21	170/20	210/30	070/10	110/25	280/45	310/15
1100	250/17	065/18	290/20	300/40	250/10	195/15	270/35	270/30	130/10	320/25	230/20	280/15	290/27	070/15	110/25	280/40	310/15
1200	250/15	042/13	272/16	308/31	243/16	200/17	275/35	275/30	160/7	320/25	235/23	310/15	290/35	060/10	110/20	280/40	320/18
1300	260/12	035/13	290/18	295/30	240/18	200/17	285/37	275/28	175/8	325/25	235/20	310/12	275/32	060/10	110/12	280/35	320/18
1400	200/9	045/15	270/17	290/35	265/22	200/18	295/31	280/23	185/12	280/17	235/20	310/16	275/32	060/10	260/22	275/35	320/15
1500	200/9	060/12	295/16	280/25	233/21	210/18	295/37	290/25	225/13	300/20	235/20	315/20	300/35	060/15	290/25	270/35	280/20
1600	234/10	050/13	300/20	300/30	240/21	260/20	240/35	280/20	Calm	300/17	235/15	320/20	290/32	060/15	290/30	270/35	280/20
1700	230/10	030/15	280/20	280/30	240/21	190/20	290/37	285/22	310/5	310/18	235/15	325/22	290/32	060/15	275/30	270/35	280/20
1800	250/8	030/18	285/20	280/30	255/18	190/18	310/35	280/20	325/3	320/15	235/15	315/23	250/29	060/15	275/30	270/35	280/20
1900	245/8	040/15	270/23	275/25	220/20	180/25	310/35	280/15	310/10	300/13	235/15	300/33	250/32	060/15	280/35	270/35	280/20
2000	250/8	040/20	270/20	290/26	220/18	180/25	280/35	240/13	310/10	310/13	250/12	315/40	275/28	070/20	280/35	270/35	280/20
2100	100/2	040/20	300/25	250/30	215/19	210/20	280/45	240/12	310/10	310/10	255/12	300/35	275/25	070/20	280/36	270/25	280/20
2200	120/4	040/20	300/23	290/30	215/20	189/21	280/50	265/18	300/12	315/13	230/15	300/40	275/24	070/15	280/30	270/25	280/20
2300	095/5	040/20	310/27	290/30	210/21	190/21	280/50	265/18	320/15	300/13	230/15	305/37	295/23	110/18	280/40	270/20	280/20
2400	040/10	020/25	320/32	295/25	240/23	165/20	270/45	225/18	240/15	300/10	210/15	280/26	310/25	110/14	280/40	270/20	280/30

Table VII-13. Wind direction (true) and wind speed at Nantucket Airport (°/kn)

Time	December 1976																
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0600	250/20	060/10	340/15	320/18	320/10	200/05	300/13	300/18	000/00	300/07	090/05	000/00	320/15	340/05	090/07	340/18	010/10
0700	260/15	050/08	340/15	330/16	330/10	200/08	300/14	300/15	000/00	300/06	210/10	000/00	330/15	360/05	090/09	300/15	350/10
0800	270/12	070/10	330/12	320/15	310/06	200/08	290/15	300/14	000/00	300/10	230/10	030/06	330/15	040/09	100/13	310/18	350/10
0900	260/15	080/13	320/10	320/20	330/08	220/06	300/15	290/15	000/00	300/15	210/10	030/07	320/15	050/09	120/15	310/18	310/08
1000	250/15	060/12	300/10	310/16	310/05	180/08	300/15	290/15	230/10	320/16	230/12	000/00	310/12	050/11	080/12	290/18	330/10
1100	260/20	070/10	310/12	320/15	250/00	190/09	310/20	290/16	220/10	340/18	220/10	000/00	300/20	040/10	000/00	290/15	330/18
1200	250/15	060/15	300/09	320/20	240/08	180/10	300/15	320/20	220/08	330/19	230/15	000/00	300/20	070/08	000/00	290/20	330/18
1300	260/14	050/12	300/12	320/20	210/10	180/11	290/20	300/15	280/10	320/18	230/15	000/00	300/20	050/10	330/18	280/20	330/12
1400	250/12	060/12	300/12	310/18	230/12	170/08	300/20	300/18	270/10	330/18	220/15	320/11	300/20	040/11	350/18	270/15	320/15
1500	240/10	050/12	300/12	300/18	240/12	200/10	290/20	300/16	280/10	320/15	230/15	320/09	310/25	050/10	340/20	270/15	310/18
1600	260/06	050/10	300/12	300/12	220/15	190/15	300/20	290/12	280/04	320/14	240/12	340/15	300/15	090/08	310/18	270/18	310/15
1700	270/06	020/12	300/14	300/14	240/15	190/13	300/18	290/14	330/08	320/08	230/10	340/17	310/15	080/10	320/16	270/18	310/13
1800	000/00	020/12	290/12	300/13	230/15	210/15	300/16	280/14	310/05	320/10	230/10	330/20	310/15	090/10	310/15	290/18	310/10
1900	000/00	040/12	300/10	310/18	240/12	210/12	300/15	280/10	320/04	320/10	220/10	330/20	300/18	090/10	310/15	290/18	310/12
2000	020/06	030/12	310/12	310/17	250/15	250/05	300/18	270/07	320/05	310/08	240/06	320/15	310/18	090/08	310/15	300/18	310/18
2100	000/00	030/12	310/12	320/20	250/12	200/15	300/18	270/10	320/07	320/10	220/07	330/18	300/18	110/06	310/15	310/15	310/20
2200	020/08	030/12	300/18	310/15	250/09	190/15	310/18	250/18	320/08	320/08	220/06	320/18	300/18	100/06	310/18	310/15	310/20
2300	120/06	030/15	310/18	300/12	230/08	210/10	310/20	250/15	310/08	310/08	000/00	320/15	300/18	110/10	300/15	320/15	310/20

Table VII-14. Wind direction (true) and wind speed at Nantucket USCG Light Ship (°/kn)

Time	December 1976																
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0100		090/10	040/20	320/26	340/25	250/15	220/20	300/40	260/27	300/22	340/10	220/06	260/30	290/25	100/18	290/30	270/20
0200		100/10	040/20	300/24	340/22	240/10	240/24	300/40	270/18	330/22	300/10	220/04	270/30	280/25	140/14	270/33	270/10
0300	240/30	090/10	030/10	310/24	340/20	250/10	280/18	300/40	270/10	370/22	290/10	190/10	260/35	290/25	300/13	270/36	270/06
0400		100/20	350/10	320/25	340/20	250/10	300/15	310/40	280/10	340/20	300/10	120/15	280/30	290/20	090/20	270/36	270/03
0500		100/20	310/20	310/30	340/16	210/10	230/10	290/50	000/00	330/20	300/10	150/10	310/30	270/18	080/22	270/38	250/02
0600	260/25	030/18	310/20	310/30	320/16	220/10	240/15	300/45	000/00	340/20	260/07	140/15	310/26	300/10	080/18	270/36	260/01
0700		040/18	320/20	300/30	320/14	220/10	220/15	300/40	090/04	340/20	260/05	160/15	320/26	290/03	070/18	280/36	320/01
0800		060/14	320/17	300/25	310/10	230/10	210/20	290/35	090/05	340/20	260/20	160/15	320/30	010/08	080/18	280/20	340/08
0900	270/20	040/14	330/20	320/35	310/08	230/10	200/22	290/30	320/04	320/20	240/15	170/15	340/25	090/10	080/22	280/20	000/12
1000		050/15	330/22	320/30	300/08	230/14	200/30	280/30	260/04	320/18	220/15	210/15	340/25	090/10	080/12	250/35	350/13
1100		060/16	320/16	320/30	300/05	240/10	270/40	290/35	250/04	320/18	230/18	210/15	330/25	110/15	080/11	260/30	320/15
1200	250/20	080/15	320/22	320/40	260/05	220/10	270/30	310/35	180/02	310/20	230/16	220/18	280/25	080/15	270/11	250/30	340/15
1300		080/15	310/15	320/30	250/15	200/15	290/35	300/25	180/04	340/25	240/20	230/10	300/30	090/18	260/20	250/30	300/16
1400		080/15	290/20	330/25	240/15	170/15	300/40	300/30	170/04	330/20	240/20	270/12	300/30	080/18	330/28	260/32	280/18
1500	250/10	080/15	290/12	320/30	240/20	170/15	300/40	310/20	180/04	340/18	240/20	320/12	300/30	090/20	280/25	270/30	300/20
1600		080/15	280/20	320/30	270/27	190/17	310/35	310/20	000/00	340/20	230/18	320/20	280/30	060/20	270/27	260/30	260/22
1700		080/15	300/22	320/30	170/20	180/20	280/30	280/18	000/00	320/20	260/18	340/26	290/31	070/20	270/30	260/26	290/29
1800	270/08	050/20	320/20	320/30	210/20	140/20	280/40	280/10	320/06	330/20	260/05	350/35	290/35	070/20	270/30	270/36	
1900	310/10	040/20	310/25	320/30	210/20	190/20	280/35	300/15	320/06	340/20	260/12	340/30	300/35	080/18	270/32	270/38	
2000	310/04		290/20	320/30	240/20	200/20	250/30	250/10	350/06	340/10	010/10	340/35	320/35	080/20	270/32	270/35	
2100	170/04	030/20	300/20	310/30	240/20	200/24	240/40	240/15	340/12	310/14	070/10	340/40	310/35	070/16	270/30	270/30	
2200	170/07	060/25	310/22	310/30	250/20	220/20	280/40	250/20	340/15	300/10	140/04	330/40	310/35	090/16	270/32	260/20	
2300	080/08	060/25	330/23	310/25	240/18	220/20	270/40	250/20	330/20	300/10	170/04	310/25	330/35	090/20	260/36	270/22	
2400	100/05	030/20	330/26	330/20	240/18	210/18	290/40	250/27	300/22	290/15	210/06	290/26	310/30	090/20	270/36	280/20	

Table VII-15. Zooplankton species abundance observed on *Delaware II* cruise 76-13 at stations located in vicinity of *Argo Merchant* (Figure 4-1)

Species	Stations → / Life Stage*	4	5	6	7	8	9
		Number/100 m^3					
Calanus finmarchicus	000	106	348	175	973	584	1097
	054			9	21		
	052					255	
Centropages typicus	000	5072	4018	753	342	584	5119
	054	740	52	94	32		
	052					218	4388
Centropages hamatus	000	1162	70	27	35	36	2560
Pseudo-paracalanus	000	21874	3809	94	317	23134	126519
	054	16274	470				63625
Metridia lucens	000		313	36	56	36	
	052			58	78	730	365
Temora longicornis	000	106	52	4	14		
Rhincalanus coronutus	000				4		
Oithona sp.	000					328	731
Acartia sp.	000	106					
Calanus minor	000						365
Tortanus discaudatus	000				4		
Alteutha depressa	000	317	104			36	
Sagitta elegans	000		52	395	102	73	
Sagitta serratodentata	000			45	95		
Sagitta spp.	000				4		
Parathemisto sp.	000			112			
	052	106					
	054				35		
Monoculodes sp.	054						731
Gammaridae	054	2959	52				
Gammaridea	000			103			
	054				4		
Crangon septemspinosa	000			4			
Cumacea	054	106					
Cirripedia	013	106					
Asteroidea	054						365
Gastropoda	000				7		1462
Pteropoda	000				7		
Foraminifera	000	528	209			1314	365
Molts		4650	70				
Fish eggs	054	211	17		14	292	365
Ammodytes americanus	054	1585	2922	350	222	620	18648
Total		51358	12488	2259	2352	28240	225974

* 000 - Adult (large)
054 - Copepodite stages I-III (medium)
052 - Copepodite stages IV and V (small)
013 - Nauplius

Table VII-16. Numbers of fish eggs and larvae per sample collected in the area of the oil spill (values represent combined totals of eggs from surface and water column samples and are not standardized for volume of water strained).

	Station					
Species	4	5	6	7*	8	9
Fish eggs:						
Cod (*Gadus morhua*)	277	53	17	5	25	310
Pollock (*Pollachius virens*)	5	59	13	32	1139	115
Total	282	112	30	37	1164	425
Larvae:						
Cod (*Gadus morhua*)	0	1	0	3	0	0
Pollock (*Pollachius virens*)	0	0	15	0	0	0
Sand Launce (*Ammodytes americanus*)	5890	10,641	5950	1313	1361	5953
Herring (*Clupea harengus*)	2	0	2	0	0	0
Rockling (*Enchelyopus cimbrius*)	0	1	0	0	0	0
Hake (*Urophycis sp.*)	0	0	1	0	0	1
Total	5892	10,643	5968	1316	1361	5954

* No surface sample taken; numbers are for the water column sample only.

Table VII-17. Stations on *Delaware II* cruises 76-13 and 77-01 where fish were collected for food habits analysis

Station	Date: Day	Date: Month	Date: Year	Time (EST)	N. lat. (min/deg)	W. long. (min/deg)	Depth* (m)	Wind: Dir.	Wind: Sp.	Wave hgt. (ft)	Air temp. (°C)	Surf. temp.* (°C)	Bott. temp* (°C)
4	22	12	76	2380	40 49	69 30	44	24	18	6	4.4	5.7	5.7
6	23	12	76	0317	40 43	69 05	84	24	15	4	6.7	6.7	6.8
7	5	01	77	0835	41 22	69 30	32	36	24	5	2.8	4.7	4.7
9	5	01	77	1330	41 23	69 10	144	36	15	5	3.9	6.6	7.1
10	5	01	77	1608	41 22	68 51	126	36	14	4	4.4	6.7	7.1
11	5	01	77	1800	41 27	68 39	96	33	8	4	3.3	6.6	6.8
12	5	01	77	2112	41 22	68 15	50	32	15	2	3.3	5.4	5.8
14	6	01	77	0105	41 10	67 38	51	34	10	3	4.4	5.4	6.4
15	6	01	77	0250	41 15	67 24	49	35	16	3	3.9	5.7	5.8
17	6	01	77	0737	41 21	66 57	66	03	20	4	3.9	5.9	5.9
18	6	01	77	0945	41 27	66 42	66	01	20	3	2.8	6.3	6.5
19	6	01	77	1215	41 10	66 55	70	03	17	4	3.9	6.1	5.8
22	6	01	77	1742	40 43	66 57	143	05	10	4	2.2	8.4	9.1
24	6	01	77	2333	40 45	67 21	97	36	-	2	2.2	6.7	6.9
27	7	01	77	0505	41 04	67 45	54	10	8	2	3.9	5.3	6.1
29	8	01	77	2037	40 46	69 57	26	32	18	4	0.6	4.1	4.1
31	8	01	77	2353	41 06	69 36	31	31	18	4	-2.2	5.4	5.4
32	9	01	77	0153	40 56	69 34	39	31	20	4	-1.7	4.7	4.9
33	9	01	77	0405	40 41	69 41	52	30	18	4	-2.2	5.4	5.4
36	9	01	77	1030	40 42	68 56	67	29	20	4	0.0	5.9	5.9

*Depth, surface and bottom temperature as recorded from XBT trace.

Table VII-18. Stomach contents of fish species, as percent weight, collected during *Delaware II* cruise 76-13

Stomach contents	Spiny dogfish	Little skate	Winter skate	Atlantic cod	Ocean pout	Windowpane
HYDROZOA	+	+	-	+	0.4	0.1
NEMATODA	-	+	0.1	+	0.2	-
POLYCHAETA	-	8.0	21.8	4.0	16.9	-
Opheliidae	-	0.6	21.8	-	-	-
Aphroditidae	-	-	-	3.9	16.9	-
Glyceridae	-	0.6	-	-	-	-
Maldanidae	-	0.7	-	-	-	-
Other Polychaeta	-	6.1	-	0.1	-	-
CRUSTACEA	-	84.2	2.0	62.0	29.4	96.8
Cancridae	-	2.9	-	6.9	28.7	-
Crangonitae	-	4.5	-	4.3	-	3.3
Paguridae	-	12.5	-	0.3	-	-
Pandalidae	-	-	-	0.7	-	-
Other decapoda	-	-	-	1.5	-	3.3
Gammaridea	-	63.8	+	47.8	0.7	90.2
Caprellidea	-	+	-	-	-	-
Isopoda	-	0.5	2.0	0.5	+	-
MOLLUSCA	0.3	5.3	-	0.7	0.3	-
Pelecypoda	-	0.2	-	0.7	0.3	-
Cephalopoda	0.3	5.1	-	-	-	-
ECHINODERMATA	-	-	-	0.7	16.6	-
Strongylocentrotus	-	-	-	-	0.7	-
Echinarachnius	-	-	-	0.7	15.9	-
PISCES	99.7	-	50.3	27.6	-	2.9
Ammodytes amer.	7.6	-	50.3	25.7	-	-
Other Pisces	92.1	-	-	1.9	-	2.9
MISCELLANEOUS	-	2.5	25.8	5.0	4.1	0.2
SAND and ROCKS	-	-	-	-	32.1	-
# Stomachs	9	40	7	26	4	5
# Empty	6	2	0	1	0	0
$\overline{X}$ wt per stomach(g)	4.93	2.41	10.99	3.90	7.48	3.13
Length range (cm)	76-99	30-49	52-94	35.86	46-69	27-38

+ indicates <0.1%

Table VII-19. Part I-- stomach contents of fish species as percent weight, collected during *Delaware II* cruise 77-01

Stomach contents	Spiny dogfish	Little skate	Winter skate	Thorny skate
COELENTERATA	-	0.6	-	-
Cerianthidae	-	-	-	-
Other coelenterates	-	0.6	-	-
POLYCHAETA	-	19.5	60.7	29.5
Aphroditiae	-	1.1	-	2.3
Other polychaetes	-	18.4	60.7	27.2
CRUSTACEA	+	48.1	0.8	4.1
Caprellidea	-	-	-	-
Gammaridea	+	28.0	-	+
Hyperidea	-	-	-	-
Cancridae	-	5.1	-	-
Crangonidae	-	5.9	-	-
Paguridae	-	4.5	-	4.1
Pandalidae	-	-	0.7	-
Isopoda	-	3.6	-	-
Euphausiacea	+	-	-	-
Other Crustacea	-	1.0	0.1	-
MOLLUSCA	2.7	1.4	24.9	0.1
Pelecypoda	-	1.4	24.9	-
Gastropoda	-	-	-	-
Cephalopoda	2.7	-	-	0.1
ECHINODERMATA	-	-	-	-
Echinoidea	-	-	-	-
Ophiuroidea	-	-	-	-
PISCES	97.3	15.5	12.9	43.4
Cottidae	-	-	-	-
Gadidae	52.6	15.5	-	-
Ammodytidae	-	-	3.0	-
Other fish	44.7	-	9.9	43.4
MISCELLANEOUS	-	14.9	-	22.9
SAND and ROCKS	-	-	0.7	-
# Stomachs	10	23	2	4
# Empty	4	5	0	0
$\overline{X}$ wt. per stomach	5.28	1.38	19.41	17.28
length range(cm)	43-95	44-51	77-87	73-85

+ indicates <0.1%

Table VII-19. Part II--stomach contents of fish species, as percent weight, collected during *Delaware II* cruise 77-01

Stomach contents	Red hake	Haddock	Pollock	Atlantic cod	Ocean pout
COELENTERATA	-	59.5	-	+	0.1
Cerianthidae	-	59.5	-	-	-
Other coelenterates	-	-	-	+	0.1
POLYCHAETA	-	24.2	-	2.8	9.0
Aphroditiae	-	-	-	2.7	9.0
Other polychaetes	-	24.2	-	0.1	-
CRUSTACEA	81.1	1.4	29.6	38.7	9.8
Caprellidea	-	+	-	-	-
Gammaridea	-	0.8	0.1	14.8	2.1
Hyperidea	-	-	0.1	+	-
Cancridae	23.7	-	-	6.6	6.0
Crangonidae	1.0	+	0.5	3.1	-
Paguridae	-	0.4	-	10.3	-
Pandalidae	-	-	7.0	0.4	0.2
Isopoda	-	0.2	-	0.3	0.1
Euphausiacea	-	-	0.3	-	-
Other Crustacea	56.4	+	21.6	3.2	1.4
MOLLUSCA	1.0	2.0	+	2.3	+
Pelecypoda	1.0	1.9	-	0.8	+
Gastropoda	-	0.1	-	1.5	-
Cephalopoda	-	-	+	-	-
ECHINODERMATA	-	1.3	-	-	79.6
Echinoidea	-	0.1	-	-	79.6
Ophiuroidea	-	1.2	-	-	-
PISCES	-	1.6	69.8	53.3	-
Cottidae	-	-	0.5	-	-
Gadidae	-	-	-	-	-
Ammodytidae	-	1.6	68.0	20.8	-
Other fish	-	-	1.3	32.5	-
MISCELLANEOUS	-	0.4	0.2	2.8	1.0
SAND and ROCKS	17.9	9.6	0.4	0.1	0.5
#Stomachs	6	21	10	39	13
#Empty	1	2	0	2	1
$\overline{X}$ wt. per stomach	1.75	11.33	22.95	19.37	13.93
length range(cm)	31-35	34-72	28-87	33-100	53-81

Table VII-19. Part III--stomach contents of fish species, as percent weight, collected during *Delaware II* cruise 77-01

Stomach contents	Windowpane flounder	American plaice	Winter flounder	Yellowtail flounder
COELENTERATA	-	-	-	-
Cerianthidae	-	-	-	-
Other coelenterates	-	-	-	-
POLYCHAETA	4.5	93.5	-	12.5
Aphroditiae	-	93.5	-	-
Other polychaetes	4.5	-	-	12.5
CRUSTACEA	43.1	-	-	66.1
Caprellidea	-	-	-	-
Gammaridea	0.4	-	-	4.9
Hyperidea	-	-	-	-
Cancridae	-	-	-	-
Crangonidae	41.6	-	-	60.8
Paguridae	-	-	-	0.4
Pandalidae	-	-	-	-
Isopoda	0.1	-	-	-
Euphausiacea	1.0	-	-	-
Other Crustacea	-	-	-	-
MOLLUSCA	-	-	-	4.1
Pelecypoda	-	-	-	4.1
Gastropoda	-	-	-	-
Cephalopoda	-	-	-	-
ECHINODERMATA	-	6.5	-	-
Echinoidea	-	-	-	-
Ophiuroidea	-	6.5	-	-
PISCES	28.2	-	-	0.3
Cottidae	-	-	-	-
Gadidae	-	-	-	-
Ammodytidae	28.2	-	-	-
Other fish	-	-	-	0.3
MISCELLANEOUS	24.2	-	-	9.5
SAND and ROCKS	-	-	-	7.5
#Stomachs	28	5	5	19
#Empty	17	3	5	1
$\bar{X}$ wt. per stomach	0.38	0.43	0	0.39
length range (cm)	27-38	28-48	33-46	26-41

Table VII-19. Part IV--stomach contents of fish species, as percent weight, collected during *Delaware II* cruise 77-01

Stomach contents	Alewife		Sea raven		Longhorn sculpin	
COELENTERATA	+		0.1		-	
Cerianthidae		-		-		-
Other coelenterates		+		0.1		-
POLYCHAETA	-		-		0.5	
Aphroditiae		-		-		-
Other polychaetes		-		-		0.5
CRUSTACEA	99.1		0.4		98.5	
Caprellidea		-		-		-
Gammaridea		96.4		-		0.1
Hyperidea		0.2		-		-
Cancridae		-		-		-
Crangonidae		-		0.4		5.5
Paguridae		-		-		-
Pandalidae		-		-		65.6
Isopoda		-		-		-
Euphausiacea		2.2		-		-
Other Crustacea		0.5		-		27.3
MOLLUSCA	-		0.2		-	
Pelecypoda		-		-		-
Gastropoda		-		-		-
Cephalopoda		-		0.2		-
ECHINODERMATA	-		-		-	
Echinoidea		-		-		-
Ophiuroidea		-		-		-
PISCES	-		99.3		0.3	
Cottidae		-		60.8		-
Gadidae		-		2.0		-
Ammodytidae		-		-		-
Other fish		-		36.5		0.3
MISCELLANEOUS	0.9		-		0.7	
SAND and ROCKS	-		-		-	
#Stomachs	10		5		12	
#Empty	0		2		2	
$\bar{X}$ wt. per stomach	2.54		15.34		0.95	
length range (cm)	22-49		22-49		18-22	

Table VII-20. Biological samples for GC-MS analysis

Type of Sample	Group 1 Cruise	Group 1 Station	Group II Cruise	Group II Station
Fish:				
Cod	DE 77-01	3	DE 77-01	38
Haddock	"	8	"	27
Silver hake	"	3	"	24
Red hake	"	10	"	24
Yellowtail flounder	"	3	"	31
Winter flounder	"	3	"	31
Windowpane flounder	"	3	DE 76-13	4
Invertebrates:				
Sea scallops	"	3	DE 77-01	39
Lobster	"	6	DE 76-13	6
Sand dollar	"	19	DE 77-01	34
Special samples:				
Contents of cod stomach containing oil	"	29		
Winter flounder with external smudge of oil	DE 76-13	4		

Table VII-21. Oiled birds collected from Nantucket and Cape Cod, December 21, 1976, to January 23, 1977

Species	Live	Dead
Murre (all species)	45	25
Common Loon	19	12
Razor-billed Auk	18	5
Great Black-backed Gull	5	11
Herring Gull	1	7
Common Eider		4
Gannet	2	
Kittiwake	1	1
Miscellaneous (three species)	1	2
Total	92	68

Table VII-22. Observations of marine mammals

Date, time, contributor	Location (Appendix IV ref.)	No. obs.	Dir. of Travel	Description species	Depth at location (fathoms)	Sea temp. (°C)	Sighting distance Beaufort scale	Position relative to oil (nearest pancake)
12/16 Loughlin	41°02'N 69°27.5'W	1		Finback	?	5	1/4 mi	Within 3 mi of of *Argo Merchant* No oil present
12/20 1340 Winn	Muskegot Is.	1	--	Possible grey seal	-	--	-	-
12/21 1151 Deaver	41°36.5'N 69°16.8'W (Map IV-5)	1	N	Straight spout-sounding-no tail-black-no white 30-40' (prob. finback)	30	5.6	Overhead	38 mi N
12/22 1245	40°41.2'N 68°30.0'W (Map IV-6)	1	--	Tall, straight spout-black-no white-no flukes 30-40' (prob. finback)	32	--	Overhead	1.4 mi S
12/23 1156 Deaver	40°30.3'N 67°05.5'W (Map IV-7)	1	--	Tall, straight spout-black no white-no flukes 30-40' (prob. finback)	250	10.6	Overhead	28.8 mi SE
1401 Teal	41°00'N 68°33'W (Map IV-7)	2	--	Narrow-black-no white-no flukes-both 40'+ (prob. finbacks)	27	--	Overhead	Just inside oil area from N
12/24 1040 Deaver	41°28.3'N 69°12.7'W (Map IV-8)	1	--	Black-no white-no flukes 30-40' (prob. finback)	82	5.7	Overhead	25.5 mi N
12/24 Loughlin	41°02'N 69°27.5'W	2	--	Finback	?	5	1/4 mi	Within 3 mi of *Argo Merchant*

Table VII-22. Observations of marine mammals (continued)

Date, time, contributor	Location (Appendix IV ref.)	No. obs.	Dir. of Travel	Description species	Depth at location (fathoms)	Sea temp. (°C)	Sighting distance Beaufort scale	Position relative to oil (nearest pancake)
1/1/77	No flight							
1/2/77 1110 Anthony	40°21.3'N 66°58'W	2	WSW	Propoise-black on back 5-10' (L. acutus)	1440	8.2	4-5	20 mi N of 1% conc.
1157 Baxter	39°13.1'N 66°12.9'W	3	--	Three simul. spouts--tall, straight (prob. finbacks)	2514	14.3	3-4	In 1% conc.
1/3/77 0920 Baxter	41°05.0'N 69°25.0'W	2	--	Squat spout--(rorqual)	16	3.9	1	In 1% conc. 3 mi from *Argo Merchant*
1019 Anthony	39°28.9'N 68°20.5'W	1	SE	Black to gray--white sudos 6-7' (L. Acutus)	1630		1	40 mi S of 1% conc.
1033 Anthony	39°17'N 67°34.5'W	1	NNE	All black--no white flippers large (prob. finback)	1900	15.2	1	5 mi W of 1% conc.
1101 Pilot	39°21.8'N 66°20.0'W	1		Long, black, slender-slow-resting-70'+ (finback)	2350	14.0	1	2 mi E of slick
1145 Anthony	40°16.5'N 66°36.5'W	1	ENE	Black back-tail visible-circ. footprint (rorqual)	1460	7.7	1	10 mi N of 2-3% pancakes
1212 Anthony	40°34.5'N 66°36.5'W	1	SW	Porpoise--grayback--white (L. acutus)	1100	8.4	1	20 mi N of 2-5% pancakes
1224 Baxter-Anthony	40°22.0'N 67°56.0'W	10-12	N	Pilot whales	367	9.0	1	In 1% area

Table VII-22. Observations of marine mammals (continued)

Date, time, contributor	Location (Appendix IV ref.)	No. obs.	Dir. of Travel	Description species	Depth at location (fathoms)	Sea temp. (°C)	Sighting distance Beaufort scale	Position relative to oil (nearest pancake)
1228 Anthony	40°30'N 68°03'W	1		Propoise--gray back--white (L. acutus)		65	1	In 1% area
1/4/77	No sightings							
1/5/77	No sightings							
1/6/77 1030 Baxter	40°37'N 71°35'W	1	ESE	Finback		39	Overhead 1-2	60 mi SW of *Argo Merchant*
1/1/77	No flights							
1/8/77	No flights							
1/9/77	No flights							
1/10/77	No flights							
1/11/77	No flights							
1/12/77 1430 Orson	38°50'N 65°58'W	3		Pilot whales			Overhead 2-3	In 0.5% conc.
1/13/71	No sightings							

Table VII-22. Observations of marine mammals (continued)

Date, time, contributor	Location (Appendix IV ref.)	No. obs.	Dir. of Travel	Description species	Depth at location (fathoms)	Sea temp. (°C)	Sighting distance Beaufort scale	Position relative to oil (nearest pancake)
12/25								
12/26								
12/27								
12/28	No flight							
12/29	No flight							
12/30	No flight							
12/31 1129 Time-Life photog:	39°48.1'N 67°42.0'W (Map IV-12)	1	--	Spout only-tail, straight (prob. finback)	1450	16.0	1/2 mi 3-4	10 mi S
1300 Pilot	40°15.0'N 67°44.0'W	2	N	Large porpoise- 8-10'- black (prob. Lagenorhynchus acutus)	400	10.5	Overhead 3-4	Within lightly striated area
1409 Baxter	40°33.5'N 67°43.2'W (Map IV-12)	1	--	Spout only-tall, straight (prob. finback)	50	10.0	1 mi 3-4	Within 2% conc. area
1415 Baxter	40°43.9'N 67°35.0'W (Map IV-12)	1	SSW	Straight spout - finback dorsal - 40-50'+ (finback)	145	6.0	3/4 mi 3-4	10 mi N
1425 Baxter	40°55.0'N 67°33.0'W (Map IV-12)	2	N	Finbacks	35	5.5	2-3 mi 2-3	25.5 mi N

✿ U. S. GOVERNMENT PRINTING OFFICE 1976 - 778-505 Reg. 8

DATE DUE

GAYLORD	No. 2333		PRINTED IN U.S.A.